

ARMY STTR 10.A PROPOSAL SUBMISSION INSTRUCTIONS

The United States Army Research Office (ARO) manages the Army's Small Business Technology Transfer (STTR) Program. The following pages list approved topics for the fiscal year 2010 STTR Program. Proposals addressing these areas will be accepted for consideration if they are received no later than the closing date and hour of this solicitation.

The Army anticipates funding one or two STTR Phase I contracts to small businesses with their partner research institutions in each topic area. Awards will be made on the basis of technical evaluations using the criteria contained in this solicitation and the availability of Army STTR funds. If no proposals within a given area merit support relative to those in other areas, the Army will not award any contracts for that topic. Phase I contracts are limited to a maximum of \$100,000 over a period not to exceed six months.

Please Note!

The Army requires your entire proposal to be submitted electronically through the DoD-wide SBIR/STTR Proposal Submission Web site (<http://www.dodsbir.net/submission>). A hardcopy is NOT required. Hand or electronic signature on the proposal is also NOT required. In this solicitation, Army has established a 20-page limitation for proposals submitted in response to their topics.

The DoD SBIR/STTR Proposal Submission system (available at <http://www.dodsbir.net/submission>) will lead you through the preparation and submission of your proposal. Refer to section 3.0 at the front of this solicitation for detailed instructions on Phase I proposal format. You must include a Company Commercialization Report as part of each proposal you submit; however, it does not count against the proposal page limit. If you have not updated your commercialization information in the past year, or need to review a copy of your report, visit the DoD SBIR/STTR Proposal Submission site. Please note that improper handling of the Commercialization Report may result in the proposal being substantially delayed and that information provided may have a direct impact on the review of the proposal. Refer to section 3.5d at the front of this solicitation for detailed instructions on the Company Commercialization Report.

If you collaborate with a university, please highlight the research that they are doing and verify that the work is FUNDAMENTAL RESEARCH.

Be reminded that if your proposal is selected for award, the technical abstract and discussion of anticipated benefits will be publicly released on the Internet. Therefore, do not include proprietary or classified information in these sections. DoD will not accept classified proposals for the STTR Program. Note also that the DoD web site contains data on all past DoD SBIR/STTR Phase I and II awards. This information can be viewed on the DoD SBIR/STTR Awards Search Web site at www.dodsbir.net/awards.

Based upon progress achieved under a Phase I contract, utilizing the criteria in DoD solicitation preface Section 4.3, "Evaluation Criteria Phase II" a firm may be invited to submit a Phase II proposal (however, Fast Track Phase II proposals do not require an invitation – see Section 4.5 of this solicitation). Phase II proposals should be structured as follows: the first 10-12 months (base effort) should be approximately \$375,000; the second 10-12 months of funding should also be approximately \$375,000. The entire Phase II effort should generally not exceed \$750,000. Contract structure for the Phase II contract is at the discretion of the Army's Contracting Officer after negotiations with the small business.

The Army does not issue interim or option funding between STTR Phase I and II efforts, but will provide accelerated Phase II proposal evaluation and contracting for projects that qualify for Fast Track status.

Army STTR Contracts may be fully funded or funded using options or incremental funding.

CONTRACTOR MANPOWER REPORTING (CMR) (Note: Applicable only to U.S. Army issued STTR contracts)

Accounting for Contract Services, otherwise known as Contractor Manpower Reporting (CMR), is a Department of Defense Business Initiative Council (BIC) sponsored program to obtain better visibility of the contractor service workforce. *This reporting requirement applies to all STTR contracts issued by an Army Contracting Office.*

Offerors are instructed to include an estimate for the cost of complying with CMR as part of the cost proposal for Phase I (\$100,000 max) and Phase II (\$750,000 max), under “CMR Compliance” in Other Direct Costs. This is an estimated total cost (if any) that would be incurred to comply with the CMR requirement. Only proposals that receive an award will be required to deliver CMR reporting, i.e. if the proposal is selected and an award is made, the contract will include a deliverable for CMR.

To date, there has been a wide range of estimated costs for CMR. While most final negotiated costs have been minimal, there appears to be some higher cost estimates that can often be attributed to misunderstanding the requirement. The STTR Program desires for the Government to pay a fair and reasonable price. This technical analysis is intended to help determine this fair and reasonable price for CMR as it applies to STTR contracts.

- The Office of the Assistant Secretary of the Army (Manpower & Reserve Affairs) operates and maintains the secure CMR System. The CMR Web site is located here: <https://contractormanpower.army.pentagon.mil/>.
- The CMR requirement consists of the following 13 items, which are located within the contract document, the contractor's existing cost accounting system (i.e. estimated direct labor hours, estimated direct labor dollars), or obtained from the contracting officer representative:
 - (1) Contracting Office, Contracting Officer, Contracting Officer's Technical Representative;
 - (2) Contract number, including task and delivery order number;
 - (3) Beginning and ending dates covered by reporting period;
 - (4) Contractor name, address, phone number, e-mail address, identity of contractor employee entering data;
 - (5) Estimated direct labor hours (including subcontractors);
 - (6) Estimated direct labor dollars paid this reporting period (including subcontractors);
 - (7) Total payments (including subcontractors);
 - (8) Predominant Federal Service Code (FSC) reflecting services provided by contractor (and separate predominant FSC for each subcontractor if different);
 - (9) Estimated data collection cost;

- (10) Organizational title associated with the Unit Identification Code (UIC) for the Army Requiring Activity (The Army Requiring Activity is responsible for providing the contractor with its UIC for the purposes of reporting this information);
 - (11) Locations where contractor and subcontractors perform the work (specified by zip code in the United States and nearest city, country, when in an overseas location, using standardized nomenclature provided on Web site);
 - (12) Presence of deployment or contingency contract language; and,
 - (13) Number of contractor and subcontractor employees deployed in theater this reporting period (by country).
- The reporting period will be the period of performance not to exceed 12 months ending September 30 of each government fiscal year and must be reported by 31 October of each calendar year.
 - According to the required CMR contract language, the contractor may use a direct XML data transfer to the Contractor Manpower Reporting System database server or fill in the fields on the Government Web site. The CMR Web site also has a no-cost CMR XML Converter Tool.
 - The CMR FAQ explains that a fair and reasonable price for CMR should not exceed 20 hours per contractor. Please note that this charge is PER CONTRACTOR not PER CONTRACT, for an optional one time set up of the XML schema to upload the data to the server from the contractor's payroll systems automatically. This is not a required technical approach for compliance with this requirement, nor is it likely the most economical for small businesses. If this is the chosen approach, the CMR FAQ goes on to explain that this is a ONE TIME CHARGE, and there should be no direct charge for recurring reporting. This would exclude charging for any future Government contract or to charge against the current STTR contract if the one time set up of XML was previously funded in a prior Government contract.
 - Given the small size of our STTR contracts and companies, it is our opinion that the modification of contractor payroll systems for automatic XML data transfer is not in the best interest of the Government. CMR is an annual reporting requirement that can be achieved through multiple means to include manual entry, MS Excel spreadsheet development, or use of the free Government XML converter tool. The annual reporting should take less than a few hours annually by an administrative level employee. Depending on labor rates, we would expect the total annual cost for STTR companies to not exceed \$500 annually, or to be included in overhead rates.

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Army STTR 10.A Topic Descriptions

A10a-T001

TITLE: Ultrafine Grained Steel and Nickel Based Alloy Manufacturing

TECHNOLOGY AREAS: Materials/Processes

The technology within this topic is restricted under the International Traffic in Arms Regulation (ITAR), which controls the export and import of defense-related material and services. Offerors must disclose any proposed use of foreign nationals, their country of origin, and what tasks each would accomplish in the statement of work in accordance with section 3.5.b.(7) of the solicitation.

OBJECTIVE: This topic seeks to significantly increase the strength, ductility and fracture toughness of high strength steel and nickel based alloys by developing a manufacturing process that produces ultrafine or nano- sized grain structures in sizes and shapes useful for advanced weapons systems components.

DESCRIPTION: High strength steel and nickel based alloys are used in a multitude of advanced weapons systems where lightweight, high power density mechanical power transmission systems are required. Components such as gears, bearings and shafts could be made significantly smaller and more durable if a major improvement in steel or nickel based alloy mechanical properties could be achieved. A significant refinement in grain size (down to the nano level) is thought to be a promising method for achieving fundamental improvements in mechanical properties. Grain size is known to have a significant effect on the mechanical behavior of materials, in particular, on the yield stress. The dependence of yield stress on grain size in metals is well established in the conventional polycrystalline range (micrometer and larger sized grains). The Hall-Petch relationship ($Y_s = F_s + k_d^{-1/2}$) predicts that the yield stress increases with the inverse of the square root of the grain size. In this equation, "Ys" is the Yield Stress, "Fs" is the Friction Stress, "k" is a Constant, and "d" is the Grain Size. One of the most promising methods of achieving extreme grain refinement is by subjecting the material to Severe Plastic Deformation (SPD). Pioneering work in this field was conducted by Dr. Percy W. Bridgeman in the early 1940's. Dr. Bridgeman was awarded the Nobel Prize in Physics in 1946 for his work in the field of high pressure physics which showed that many materials experience fundamental changes in crystalline structure and physical properties under the ultra high pressures and shearing stresses of SPD. The advantage of SPD processed materials lies in the fact that ductility and fracture toughness may be better than those of nanostructured or ultra fine grained materials processed by other techniques. SPD also offers the potential for this refinement to be uniform through the thickness of the material versus only in a thin layer on the surface. In certain cases, the fracture toughness and the ductility is comparable or even better than typically found in low strength coarse grained materials. Thus, it is believed that SPD offers a way to realize the longstanding dream of material scientists for an ultra high strength material with excellent ductility and toughness.

There are several known processes for creating SPD of the magnitude required to achieve nanostructured grain refinement. These include High Pressure Torsion (HPT), Equal Channel Angular Pressing (ECAP) and Cyclic Channel Die Compression (CCDC). While each of these processes has its own set of advantages and disadvantages, they have all been limited to making relatively small size samples (small pellets or thin ribbons) suitable for laboratory analysis only. This topic seeks to develop an innovative SPD process that can produce nanograined steel alloy materials in quantities and sizes useful for production of advanced weapons systems components.

PHASE I: Phase I effort shall focus on demonstrating the feasibility of creating a 6 cubic inch (minimum) specimen of a steel or nickel based alloy with a ultrafine or nanograin structure by use of a SPD process. Particular alloys of interest are AISI 4340, AERMET 100, AISI 9310, and 17-4PH, and Inconel 718. Effort should include design and analysis of the proposed SPD equipment. The processing of small scale specimens (6 cubic inches or more) using the proposed SPD method and subsequent analysis/examination of the specimens for evidence of the formation of an ultrafine or nanograined structure is desired. Limited testing to verify the potential for increased mechanical properties of the ultrafine or nanograined alloy material is desired. The design and analysis of the proposed SPD equipment should consider the capability to scale up the process to produce materials of sizes usable for weapons systems components.

PHASE II: Phase II effort shall consist of further design and analysis of the equipment required producing usable sizes and quantities of the ultrafine or nanograined alloy material. Additional testing of the material produced in

Phase I shall be conducted to fully characterize the mechanical and physical properties versus a conventional macro grain sized alloy. The microstructural stability of the ultrafine or nanograined alloy when subjected to repeated stress and thermal cycling, and manufacturing processes such as forging and heat treating is also of great interests and should be characterized early in the Phase II effort. Phase II effort should consist of design and manufacture of prototype SPD processing equipment capable of producing the desired material in size and quantities usable in military weapons systems. The prototype equipment shall be utilized to demonstrate the manufacture of larger sized specimens of the material. Specimen shapes of specific interest include tubes or cylinders of several feet in length and several inches in diameter which could be used for power transmission shafting or gun barrels. Disks or rings of several inches in thickness and 10 or more inches in diameter are also of interest and could be used for gears or other complex shaped mechanical parts. Physical and mechanical property testing of the material produced by the prototype equipment shall be conducted. A target initial application shall be selected and a manufacturing plan and benefits analysis performed.

PHASE III DUAL USE APPLICATIONS: The potential commercial and military applications of an ultra fine, or nanograined steel, or nickel based alloy with ultra high strength and toughness are widespread. The material could be utilized to increase the horsepower per pound of weight in the propulsion systems for all types of aircraft and ground vehicles. The material could be employed to increase the load capacity of gears, shafts, clutches, connecting rods, turbine disks and a myriad of other components. Most, if not all of these types of components are common in both commercial and military application, and thus, the dual use potential is very high.

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KEYWORDS: steel, nickel, nanocrystalline, severe plastic deformation, high pressure torsion, equal channel angular pressing, cyclic channel die compression

TPOC: Eric C. Ames
Phone: (757) 878-0040
Fax: (757) 878-0007
Email: eric.ames@us.army.mil
2nd TPOC: Matt Spies
Phone: (757) 878-5542
Fax: (757) 878-0007
Email: matt.spies@us.army.mil

A10a-T002 TITLE: Plasmonic Sensor Array

TECHNOLOGY AREAS: Sensors

The technology within this topic is restricted under the International Traffic in Arms Regulation (ITAR), which controls the export and import of defense-related material and services. Offerors must disclose any proposed use of

foreign nationals, their country of origin, and what tasks each would accomplish in the statement of work in accordance with section 3.5.b.(7) of the solicitation.

OBJECTIVE: Research surface plasmons for use as a sensor element in a 2 dimensional sensor array (possible sensor modes include: pressure, vibration, magnetic fields, electrostatic fields, RF, optical, etc.).

DESCRIPTION: The purpose of this STTR is to determine the feasibility of developing a two dimensional sensor array based on a grid of surface plasmon sensor elements (possible sensor modes include: pressure, vibration, magnetic fields, electrostatic fields, chemical, RF, optical, etc.). An example, sensor array is a 4 by 4 array of plasmon based pressure sensors. A second example is a 3 by 3 sensor array of plasmon magnetic field sensors.

PHASE I: Contractor and Research Institution shall research the feasibility of developing a 2 dimensional sensor array based on surface plasmons. Contractor and research institution shall propose a plasmon sensor array to detect one of the following: pressure, vibration, magnetic fields, electrostatic fields, chemical, RF, optical, etc.

Contractor and Research Institution shall provide a Phase I final report describing sensor array operation, estimated sensor performance, estimated operating temperature range, estimated operational vibration limits, estimated operational lifetime, estimated power required for the sensor array, and estimated signal processing to convert raw sensor data to a measurement quantity (e.g. for electrostatic field to V/m, optical sensor to W/cm², etc.).

PHASE II: Contractor and research institution shall prototype a 2 dimensional plasmonic sensor array based on the phase 1 feasibility study. Contractor and research institution shall research theoretical performance limits of the proposed 2 dimensional plasmonic sensor array. Contractor shall have an independent lab test and evaluate the performance limits of the prototype sensor with government concurrence. Contractor shall provide a copy of the test and evaluation report to the government. Contractor and research institution shall provide 2 prototype sensor arrays to the government point of contact. Contractor shall provide a preliminary datasheet for the prototype sensor. Contractor shall provide a final report describing the 2 dimensional plasmonic sensor array. Contractor and research institution shall provide a 2 day on site training for the prototype sensor array.

PHASE III DUAL USE APPLICATIONS: Military, aerospace, medical, and industrial applications are always looking for lower weight, and lower power technologies. For aerospace applications, thin film, flexible sensors can be integrated into composite materials, airframes, and attached to irregular surfaces. Thin film plasmonic sensors, offer the potential of creating an all optical sensor array. Medical and industrial applications require low power sensors, and the ability to withstand harsh environments. Thin film, sensors have the potential of providing accurate sensor measurements at low cost, and low power consumption.

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KEYWORDS: Surface plasmon, metamaterials, sensor, thin film, low power, magnetic field, electrostatic field, RF, optical

TPOC: Patrick Jungwirth
Phone: (256) 842-6919
Fax: (256) 876-7165
Email: patrick.jungwirth@us.army.mil
2nd TPOC: Mark Temmen
Phone: (256) 876-4604
Fax:
Email: mark.temmen@us.army.mil

A10a-T003 TITLE: Toxic Material Forensic Container

TECHNOLOGY AREAS: Chemical/Bio Defense, Materials/Processes

OBJECTIVE: To develop a forensic container capable of containing Chemical/Biological and Toxic Industrial Chemical threat-level contaminated articles for safe transport.

DESCRIPTION: The Department of Defense (DoD) has a need for the safe transport and handling of contaminated equipment and other items such as forensic evidence. Conventional evidence bags may contain tamper-evident designs, but if the items are contaminated with Chemical or Biological Warfare Agents (CBWA) or Toxic Industrial Chemicals (TICs), the conventional bags provide no protection against these threats. Recent materials development in the areas of impermeable materials, reactive fabrics, reactive sorbents, and seaming and sealing technologies make the design and construction of a toxic material forensic bag possible. For example, recent advances in nanoparticle development have led to materials that not only adsorb CWAs and TICs, but also destroy them, as well as BWAs. These nanoparticles could be formulated and developed for incorporation into reactive liners and fabrics for active protection and containment in fluid removal and neutralization of any toxic out gassing. Novel seaming and sealing technologies have also been developed to provide liquid and gas tight seals which are needed for complete containment of hazardous materials.

The toxic material forensic bag must be capable of containing chemical and biological threat level contaminated articles with no permeation or leakage for at least 96 hours. The bag must contain a sorbent liner to adsorb liquids and should include reactive components to actively adsorb and destroy CBWAs and TICs. The exterior of the bag must be puncture, tear, and abrasion resistant and maintain performance characteristics during and after normal decontamination operations. Initial design should be able to hold up to 50 pounds, but versatile enough to easily be adapted for smaller and larger (up to 55 gal drum) capacities. The proposed technology must include closures that not only sufficiently contain any contamination, but also contain tamper evident/tamper resistant properties. The

bag must contain tracking/logging capabilities to meet federal chain-of-custody requirements. The sealed forensic bag must be able to withstand transport on aircraft to include external air pressure changes and must meet International Air Transportation Association (IATA) standards for transportation of hazardous material.

PHASE I: Develop a toxic material Forensics bag design that meets the stated objectives listed above. Synthesize several possible fabric and sorbent materials with the desired properties and reactivity and test swatch material of the fabrics against at least two CWA simulants, 3 TICs, and one BWA surrogate. Identify potential seaming and closure technologies and tracking/logging capabilities.

PHASE II: Develop a prototype toxic material forensic bag that meets the stated objectives listed above. Optimize the best fabric and sorbent materials, as well as the best seaming and sealing technologies identified in Phase I and perform live agent testing with at least 2 CWAs, 1 BWA, and 3 TICs.

PHASE III DUAL USE APPLICATIONS: The proposed technology has potential use in numerous applications within the Department of Defense and the commercial sector. The technology could be used in containment and transfer of evidence for the Department of Homeland Security, as well as state and local authorities and HAZMAT response teams.

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KEYWORDS: forensic container, toxic industrial chemical, contaminated equipment

TPOC: Jennifer Becker
Phone: (919) 549-4224
Fax: (919) 549-4310
Email: jennifer.j.becker@us.army.mil

A10a-T004 TITLE: MEMS Based Thermopile Infrared Detector Array for Chemical and Biological Sensing

TECHNOLOGY AREAS: Chemical/Bio Defense, Sensors

OBJECTIVE: Develop a MEMS-based thermopile array based sensor for detection and identification of chemical agents and simulants (MEMS - Micro-Electro-Mechanical Systems).

DESCRIPTION: The chemical and biological defense community has the need for a small lightweight sensor for detection of chemical agents and simulants. Infrared absorption spectroscopy has proven to be a very useful tool in the detection and identification of airborne chemicals. Pattern recognition is used to compare the infrared spectrum of library molecules against the infrared spectra of airborne contaminants. In particular, chemical warfare agents and toxic industrial chemicals have distinctive absorption lines in the infrared region. Infrared spectroscopy has been used to detect chemicals at very low concentrations. Infrared spectroscopy also holds the promise of low false alarm rates due to the spectral pattern matching over a large number of spectral bins. The size, weight, and power requirements of current infrared spectrometers have limited their utility in field environments. Current infrared spectrometers are too expensive to be deployed in large numbers.

Thermopile infrared detectors are widely used in many low-cost commercial applications requiring accurate

radiometry. Thermopiles typically operate over a broad temperature range and are insensitive to drifts in substrate temperature. They are passive devices, generating a voltage output without bias or chopping. Thus, for many applications thermopile detectors can be simpler and more reliable than other infrared detectors such as bolometers, pyroelectric or ferroelectric devices. If thermopiles are read out with high-input-impedance amplifiers they exhibit very small 1/f noise since the current flow is very small. Also, they typically have high linearity over many orders of magnitude of incident infrared power. These properties make them well suited as spectral radiometers for chemical and biological defense applications. Recently it has been demonstrated that efficient thermopile sensors can be fabricated using semiconductors rather than double-metal junctions. In particular, polycrystalline silicon can be used for fabricating thermopiles. The advantage of using silicon is the possibility of employing standard integrated circuit processes.

Monolithic thermopile sensor arrays have not been developed to the extent other infrared detector arrays such as uncooled bolometer and pyroelectric/ferroelectric arrays. The potential advantages of monolithic thermopile sensor arrays include low cost, very small power consumption, small size, and high sensitivity. The ability to fabricate thermopiles arrays from polycrystalline silicon using standard integrated circuit processes holds the potential to improve infrared sensing capabilities within the DOD. The thermoelectric coefficients and resistivity of polycrystalline silicon make it a very attractive material for this application.

MEMS-fabrication of thermopile detector arrays holds the potential of providing the DOD with rugged, inexpensive, sensitive infrared sensing capabilities. In particular, the chemical and biological defenses community has an immediate need for rugged, inexpensive infrared spectrometers for chemical sensing missions. An infrared sensor designed for chemical sensing would require a thermopile array with at least 64 pixels whose size and location are optimized for spectroscopic applications. The detector array should have a large detectivity and a fast detection time constant. In order to limit 1/f noise the system should have a large resistance. Also, the substrate should behave consistently over a temperature range and have a small temperature coefficient of responsivity.

PHASE I: Design a MEMS based infrared thermopile detector array. The system should be optimized for optical applications and should provide maximum sensitivity in the thermal infrared (8 to 12 micron) region of the electromagnetic spectrum. The design should provide for at least 64 pixels and be optimized for spectroscopic applications in the infrared region. The system should have a detectivity (D^*) of 1×10^8 Jones or better. The system should have fast response with a detection time constant of 35 milliseconds or less. The system should be relatively insensitive to operating temperature and have the absolute value of the temperature coefficient of responsivity be 0.04%/C or less. In order to minimize 1/f noise the system should have a high resistance of at least 90 kohms or better. The design should include a MEMS implementation thermopile design and fabrication. A sensitivity model and prediction based on practical components should be completed.

PHASE II: Fabricate the MEMS based thermopile detector array. Design and build all necessary readout electronics. Test and characterize array. Use the results of the testing to update the MEMS thermopile array design.

PHASE III DUAL USE APPLICATIONS: There are environmental applications for a small robust, chemical sensor. A rugged, inexpensive chemical sensor will benefit the manufacturing community by providing inexpensive monitoring of chemical processes. Also, first responders such as Civilian Support Teams and Fire Departments have a critical need for a rugged, inexpensive sensor that can be transported to the field to test for possible contamination by CW agents.

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KEYWORDS: thermopile, thermocouple, infrared array, chemical detection, infrared spectroscopy

TPOC: William Clark
Phone: (919) 549-4314
Fax: (919) 549-4310
Email: william.w.clark@us.army.mil

A10a-T005 TITLE: Multi-input Multi-output Synthetic Aperture Radar with Collocated Antennas

TECHNOLOGY AREAS: Sensors

OBJECTIVE: To design a multi-input multi-output synthetic aperture radar system with collocated antennas, and to experimentally investigate performance of the system

DESCRIPTION: Radars play a vital role in many important military applications because of their suitability for a wide range of operation conditions including weather and day/night variations. Multi-input multi-output (MIMO) radar capability receives increasing interest in the research community [1-6]. A MIMO synthetic aperture radar (SAR) system differs from conventional phased array SAR in the sense that it transmits and receives multiple waveforms using multiple (both transmitting and receiving) antennas that may or may not be collocated (i.e. all antennas are implemented on the same platform). Preliminary studies indicate potential benefits of MIMO SAR such as smaller losses when observing stationary and low-velocity targets [7], reduction of shadowing effects for 3D imaging [1,4], and realization of a synergistic MIMO SAR and ground moving target indication (GMTI) capability [5].

This effort seeks the design and demonstration of a proof-of-concept MIMO SAR system with collocated antennas for area surveillance, particularly to support urban operations with dynamic complex terrains and potentially moving small targets. The intended platforms are low-flying unmanned aerial or ground vehicles. The emphasis of this effort is the design of computational algorithms for signal processing including probing waveform design and receiver signal synthesis. This effort should provide experimental understanding of MIMO SAR concept and design tradeoffs, particularly in comparison with conventional phased array radar systems.

PHASE I: The effort may be directed toward feasibility study through modeling and simulation demonstrations. Algorithms should be devised for synergistic MIMO SAR and GMTI. Candidate tasks are (1) investigation of basic probing waveform designs that facilitate the high quality image formation of various types of targets; (2) algorithm designs for received signal synthesis; (3) performance evaluations of the design in terms of imaging, target detection and localization capabilities; (4) identification of performance limitations and hardware requirements to prepare for Phase II hardware implementation. Preliminary hardware design should be in place and ready for Phase II effort.

PHASE II: Effort for Phase II should be focused on developing a prototype system based on the synergistic MIMO SAR and GMTI design. The algorithms developed in Phase I should be implemented using commercial-of-the-self

hardware components. Effort should fully investigate the effects of multiple probing waveforms that may be correlated or uncorrelated with each other on MIMO SAR performance. Optimal or adaptive waveform design should be explored. Algorithms should be further refined and adjusted to accommodate observed noise characteristics. The effort should demonstrate the performance and capability of the new system, as well as the effectiveness of the imaging algorithms for the detection and localization of different types of targets, particularly humans and ground civilian vehicles. The effort should also investigate tradeoffs between power, weight, frequency and SAR image resolution.

PHASE III DUAL-USE APPLICATIONS: Phase III will further refine algorithms and the design to improve performance robustness for practical operation scenarios. Effort may be focused on further developing the capability and transition to military programs through defense laboratories (such as the Naval Research Laboratory and the Army Research Laboratory) and/or to commercial defense companies such as General Dynamics and Lockheed Martin. Commercial applications include border patrol, homeland security, area monitoring, and coast line mapping.

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KEYWORDS: synthetic aperture radar, radar imaging, target detection and localization, multi-input multi-output radar, ground moving target indication, waveform synthesis

TPOC: Liyi Dai
Phone: (919) 549-4350
Fax: (919) 549-4248
Email: liyi.dai@us.army.mil
2nd TPOC: Rabinder Madan
Phone: (703) 696-4217
Fax: (703) 696-1331
Email: madanr@onr.navy.mil

A10a-T006 TITLE: LADAR Light Reflection Analysis for Target Surface Characterization

TECHNOLOGY AREAS: Sensors

OBJECTIVE: To develop and demonstrate algorithms for characterizing surface material, texture and other

pertinent information for multispectral LADAR-based remote target classification

DESCRIPTION: LADAR light reflection from a target is highly dependent of the properties (spectral reflectivity and texture) of the surface of the target [1-4]. Such dependence could be exploited for target recognition based on surface characterization with appropriate imaging conditions and processing algorithms. The surface light reflection is characterized by the Bidirectional Reflectance Distribution Function (BRDF) which parameterizes the directional reflectance in terms of a few parameters (~4) for each wavelength [2,5]. This topic seeks to develop a capability for characterizing and classifying surface material and texture using multispectral LADAR based on the BRDF, its generalizations, and/or other appropriate methods for automatic sensing applications. The emphasis is algorithmic analysis of spectral [3-4], polarimetric [1] and spatiotemporal properties of target surfaces. Of particular interest is the determination of the optimum or a combination of LADAR wavelengths to distinguish surface materials, especially surfaces of high interest such as telescope lenses and human skin. Effort should also address other key relevant issues such as range determination, clutter separation, and/or polarimetric effects. Novel ideas for multispectral analysis are sought. Spatial analysis of LADAR image from range returns (point cloud) is not of high priority for this effort, but may be considered as auxiliary information. Prospective offerer is expected to possess in-house capabilities for data collection and high fidelity simulation.

PHASE I: The effort may be focused on algorithm development and validation. Potential tasks are detailed BRDF modeling and the development of methods for parameter determination in appropriate wavelengths. Models should be established for target surface characterization, clutter analysis, and further target recognition for a representative selection of sample surfaces. The feasibility of multispectral LADAR-based surface classification should be established and the limitations should be explored through either theoretical analysis or simulation study.

PHASE II: Effort may be focused on full development of the capability. A range of target surfaces should be modeled through real data collection and high fidelity simulation. Classification algorithm(s) should be augmented to include those targets. Performance metrics for surface classification should be designed, tested, and implemented. A prototype system consisting of both hardware and software package should be developed that accepts real data as inputs. Advantages and limitations should be fully investigated and understood.

PHASE III DUAL-USE APPLICATIONS: Phase III may be directed toward customizing the software package for domain specific applications such as standoff detection of improvised explosive devices, terrain analysis for ground robots, counter CCD (camouflage, concealment and deception), sniper detection, precision targeting, or persistent surveillance. A fully functioning software package should be available for transition to defense laboratories and major defense contractors. Commercial applications include area monitoring, automated terrain surveying, and natural resources analysis.

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KEYWORDS: LADAR, bidirectional reflectance distribution function, target recognition, multispectral, surface characterization

TPOC: Liyi Dai
Phone: (919) 549-4350
Fax: (919) 549-4248
Email: liyi.dai@us.army.mil

A10a-T007

TITLE: Coherent Beam Combining of Mid-IR Lasers

TECHNOLOGY AREAS: Sensors

OBJECTIVE: To develop robust, high-efficiency mid-infrared lasers based laser beam combining of quantum cascade or other mid-IR laser diodes. Power outputs for room temperature continuous wave operation of several to a hundred watts are sought in the 3-5 micron and 8-12 micron bands for IRCM (Infrared Countermeasures) and stand-off sensing needs for the military.

DESCRIPTION: DARPA MTO has a high power quantum cascade laser program (QCLs) in the 4-5 micron band for IR Countermeasures (also called, IRCM). The Army supplemented this by starting work on improved QCLs in the 3-4 and 8-12 micron regimes also. Another aspect of this work is beam combining whereby several (or even hundreds) of QCLs are phase locked to create an extraordinarily high power beam with a single transverse mode. Such high power beams could be used in multiple military applications which include IRCM systems, free-space optical communications, tracking and surveillance including imaging laser radar, and laser based chemical sensing. In such systems of the future cost and power scaling are important, as well as size of the system. Thus, solutions based on integrated chip-level and even passive approaches are desired. Cost is definitely related to simplicity, and active phase locking approaches (with feedback) tend to be complex and have seen little success to date; however, active phase locking is potentially advantageous for tracking and scanning scenarios through electronic beam steering.

PHASE I: Demonstrate design of beam combined high performance mid-IR lasers arrays based on QCLs or other semiconductor lasers with power output of 3W or more (i.e. greater than state-of-the-art output power over single lasers with comparable wall-plug efficiencies). The wavelengths of interest include both the MWIR (3-5 microns) and LWIR (8-12 microns). Prototype designs should be made at one wavelength with potential application to another regime, i.e. start at one wavelength and discuss applicability to other wavelengths.

PHASE II: Develop room temperature high efficiency beam combined laser arrays in the MW/LWIR (wall-plug efficiency > 15% for beam combined lasers) with powers greater than 3W for usable single facet output. Scaling of the power for 10 – 100W should be studied and initial attempts made for achieving > 10W on a single integrated platform within the laser chip. MOCVD (Metal Organic Chemical Vapor Deposition) or other manufacturable growth and fabrication process should be used in order to produce low-cost units at high volume for multiple applications.

PHASE III: Commercialize beam combined arrays and develop full manufacturing process working with system integrators for various wavelengths and packages to meet military needs. Thermal management and power scalability should be considered here, as well as wall-plug efficiency for single lasers. Dual use (civilian) applications include free-space optical communications and biohazard monitoring.

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KEYWORDS: mid-infrared, lasers, phase-locking

TPOC: Mike Gerhold
Phone: (919) 549-4357
Fax: (919) 549-4310
Email: mike.gerhold@us.army.mil

TECHNOLOGY AREAS: Information Systems, Sensors

OBJECTIVE: Research, design and fabrication of innovative compact, potentially scalable devices for laser beam switching, deflection, scanning, and frequency shifting to address qubits for quantum computing applications and broader sensor technology.

DESCRIPTION: Arrays of qubits are anticipated to be a central feature of quantum computing architectures. Physical embodiments of these qubit arrays could be trapped neutral atoms, trapped ions, quantum dots, or other semiconductor devices. Here, the initial focus will be on trapped ions with future extensions to other types of physical qubits. Typically, qubits are manipulated (gate operations) and measured (read-out) using optical (lasers) means. Currently RF-driven acousto-optic modulators (AOMs) are used for trapped ion qubit experiments that switch/steer a laser beam onto and off of the ion and frequency shift the beam to enable sequences of gate operations. However, these devices have several shortcomings. RF-induced temperature changes of the AOM crystals cause time-dependent changes in beam position steering and deflection efficiency (time scales of the order 1 ms and longer). This causes intensity variations at the ion position that depend on duty cycle. Since duty cycle is not constant in complicated algorithms, fidelity of the operation is significantly affected. Additionally, these devices have insufficient switching speed and on/off ratios (in particular, limited extinction in the off state), high power consumption (one to several Watts of RF in the on-state), and are not compact. Innovative optical devices and technology and creative approaches are sought to overcome these shortcomings and enable the following desirable features:

- Elimination or significant reduction of temperature induced beam steering from e.g. RF switching.
- Low insertion losses in the UV. Broadband (200-400 nm) low losses are preferable, but low loss at certain wavelengths of interest (e.g. 280 nm, 313 nm, 369 nm, 397 nm) would also be useful.
- Switching duration errors smaller or equal 10 ns (to control a 1 is pi-pulse duration to better than 10⁻² infidelity). Pulse timing jitter ideally < 1 ns, but can be relaxed in certain cases (this is different than pulse duration)
- Average power extinction ratio greater than 10,000 over the duration of a 1 pi-pulse after switch-off. If possible, extinction should be even higher for longer times to guard against inadvertent slow rotations and spontaneous emission decoherence. These longer-term effects can be mitigated by cascading devices and using of mechanical shutters.
- Capability to frequency shift the laser beam by 20-40 MHz. Higher shifts broaden the applications base.
- Miniaturization and scalable mass production.

While the focus here is on the trapped ion system, similar features are needed for other types of qubits and these broaden the applications base for these devices.

PHASE I: Research and development areas include: (1) Improvements to AOM crystals to achieve desired features; (2) Alternate approaches and technology that provide comparable functionality, but avoids the shortcomings of AOM crystals; (3) Improved design and fabrication. Proposed solutions must consider needs and constraints of anticipated qubit experiments. Collaboration or consultation with experimental ion trapping groups is highly encouraged. During Phase I the following must be completed: conception and design of the device, estimates of performance, and assessments of feasibility. The proposed technology must be scalable to larger numbers of qubits.

PHASE II: Finalize design and build prototypes of the device. Provide a demonstration deployment that validates the technology at a laboratory that does suitable ion trapping experiments. The Phase-II program shall provide a plan to transition the technology to commercial development and deployment.

PHASE III DUAL USE APPLICATIONS: The technology developed here has impact on the successful demonstration of quantum computing. In addition to critical national security applications, quantum computing is anticipated to have an impact on commercial applications involving hard computational problems such as optimization, routing, planning and scheduling. The technology developed here is also anticipated to have broader

impact, such as on the development of compact sensors and telecommunications.

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KEYWORDS: acousto-optic devices, AOM crystals, quantum computing

TPOC: T R Govindan
Phone: (919) 549-4236
Fax: (919) 549-4384
Email: tr.govindan@us.army.mil

A10a-T009

TITLE: Hydrogen Reformation of Renewable Butanol for Military Applications

TECHNOLOGY AREAS: Ground/Sea Vehicles, Materials/Processes

OBJECTIVE: Develop advanced catalysts, design, and build a prototype reformer to demonstrate efficient hydrogen production from renewable butanol which can be used for fuel cells, hydrogen vehicles, and other military applications.

DESCRIPTION: The low-temperature proton exchange membrane fuel cell (PEM FC) is a candidate energy converter for a compact person-portable 20 W power system for the soldier system. The most effective PEM FC from an energy efficiency and power density perspective is the hydrogen-air system, although the supply of hydrogen remains problematical. There is need for a safe and compact hydrogen generator that is fueled by an energy-dense fuel. Butanol represents a significant opportunity as a renewable liquid fuel with multiple inexpensive production paths. DuPont and British Petroleum have recently announced that they are jointly to build a small scale butanol fuel demonstration plant. (1) It has a similar flash point as JP-8 and roughly $\frac{3}{4}$ of its energy density. When butanol is used in a fuel cell it has the potential to dramatically enhance system energy density with over twice the energy density of the currently proposed methanol fuel. Butanol could enhance fuel cell performance while simultaneously improving safety for the soldier vs. current methanol fuel cells.

The technology to reform lighter alcohols is well established, (2,3); however, the catalysts and processes to efficiently reform butanol into hydrogen for use in soldier PEM fuel cells has not been developed.(4)

PHASE I: Demonstrate experimentally a fuel processor with an optimized catalyst capable of reforming butanol to generate hydrogen using air as the oxidant and without the need for additional water. Based upon the experimental results, report and discuss the size and weight of a butanol fuel processor system (including all balance-of-plant components and packaging) to produce hydrogen at a rate and purity to support a 75 W PEM FC for 72 h.

PHASE II: Design, construct, and evaluate the performance and lifetime of a butanol-to-hydrogen fuel processor intended to supply hydrogen at sufficient rate and purity to support a 75 W PEM fuel cell system for 72 h. The complete compact fuel processor system (membrane-reactor, heat exchangers, pumps, packaging, etc.) must have a minimum fueled energy density of 3.0 kWh/kg. Demonstrate maintenance-free run times of 500 h or greater. Deliver one complete system to the Army.

PHASE III: Developments in improved hydrogen sources for fuel cells will have impact on a wide range of military uses, as well as commercial power sources such as emergency medical power supplies, recreational power, etc.

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KEYWORDS: butanol, hydrogen, fuel cell, catalyst

TPOC: Robert Mantz
Phone: (919) 549-4309
Fax: (919) 549-4310
Email: robert.a.mantz@us.army.mil

A10a-T010 TITLE: Rapid JP-8 Thermal Stability/Smoke Point Testing Methodology

TECHNOLOGY AREAS: Ground/Sea Vehicles, Materials/Processes

OBJECTIVE: Develop new rapid testing methodologies to determine either thermal stability or smoke point for JP-8 fuels to enable analytical testing and qualification of JP-8 fuels.

DESCRIPTION: Accurately ensuring the quality of JP-8 fuel in a rapid fashion is important to the Army to avoid damage of aircraft and vehicle engines. The current JP-8 specification, Military Specification MIL-DTL-83133E, specifies a variety of testing methodologies to ensure fuel quality and suitability. Over time many of the testing methods have been updated to take advantage of modern technologies and improved analytical techniques. Two test methods have lagged behind their counterparts: ASTM D1322 - Standard Test Method for Smoke Point of Kerosene Aviation Turbine Fuels, and ASTM D3241 - Standard Test Method for Thermal Oxidation Stability of Aviation Turbine Fuels (JFTOT Procedures). These tests are subject to significant operator influence and judgment.

This program is to develop a modern analytical based methodology to determine either the thermal stability or the smoke point of JP-8 fuels. The new test method must be science based, rapid, and use a minimum amount of fuel. In addition, ideally the test method would be suitable for automation and require little or no operator judgment.

PHASE I: Demonstrate a science based technique to characterize fuel thermal stability or smoke point. Conduct experiments that correlate the results from new technique to the existing ASTM test methods. Show improved precision due to reduced operator judgment.

PHASE II: Develop, build, and evaluate prototype portable analytical instrument that is capable of analyzing fuels to determine thermal stability or smoke point. Deliver prototype instrument to the government for testing and evaluation.

PHASE III: Technology developed under this SBIR could have a significant impact on military and civilian fuel distribution, testing, and quality control. The developed technology will also have applicability to the commercial aviation industry, refining, and pipeline industries.

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3. ASTM D1322 - Standard Test Method for Smoke Point of Kerosene Aviation Turbine Fuels
4. ASTM D3241 - Standard Test Method for Thermal Oxidation Stability of Aviation Turbine Fuels (JFTOT Procedures)

KEYWORDS: JP-8, fuel, smoke point, JFTOT, thermal stability

TPOC: Robert Mantz
Phone: (919) 549-4309
Fax: (919) 549-4310
Email: robert.a.mantz@us.army.mil

A10a-T011

TITLE: Activated Reactants to Reduce Fuel Cell Overpotentials

TECHNOLOGY AREAS: Ground/Sea Vehicles, Materials/Processes

OBJECTIVE: Improve the power density of fuel cell based power sources.

DESCRIPTION: The current produced by a fuel cell is primarily dependent on the rate of the electrode reactions. The rate of the reactions can be increased by expending part of the voltage developed by the fuel cell to drive the reaction; this drops the output voltage of the fuel cell and decreases the power per unit current output. The traditional method of attack to improve fuel cell performance has been to try to develop improved catalysts to lower the overall energy of activation of the fuel cell reactions. While this traditional approach has met with some success fuel cells normally operate at only about 50% of theoretical efficiency.

This topic seeks to explore whether a more fruitful approach to improving fuel cell performance would be to chemically activate some or all of the reactants, thereby increasing their energy and lessening the energy difference between the reactants and the peak of the activation barrier. The simplest way to increase the energy of the reactants is by heating them; this approach leads to many well-known problems with Nafion membranes dehydrating and losing conductivity and desirable mechanical properties. Therefore, heating of reactants is NOT an acceptable approach to this topic. Among possible alternative approaches might be use of microplasmas, ultrasound, photonic irradiation, or use of chemical additives that promote activation of the reactants; this list only provides a few examples and is by no means exhaustive.

Since all approaches to activate reactants carry weight and/or power penalties it is important to provide reasonable assurance that the overall power and/or energy density of the power system is improved. The weight/power penalties of additional subsystems tend to be a larger fraction of system weight as total system power decreases. Therefore, for fuel cells that operate on standard logistics fuel (JP-8) the systems under consideration can range up to multikilowatts paralleling the family of standard military tactical generators. For fuel cells that operate on non-standard fuels the systems under consideration should be in the 1000 W and below class.

PHASE I Deliverables: Final report documenting experiments showing that proposed approach to activated reactants does improve the electrochemical fuel cell reactions, and a containing a cogent description describing how the hardware subsystem required to carry out the proposed activation can be miniaturized to the point where system power and/or energy density is improved.

PHASE II Deliverables: The effort should result in a full or subscale multi-cell stack that demonstrates the value of activated reactants in an engineering prototype. The supporting hardware required to carry out the activation must be packaged well enough to allow for reasonable estimates of the overall power source size range (measured in watts) for which the approach will be practical.

PHASE III Deliverables: Complete fuel cell based power source that incorporates activated reactants and all associated hardware in an integrated package with performance, endurance and safety data to support sales of the system.

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KEYWORDS: fuel cell, activation, reactants, ORR, oxygen reduction reaction, overpotential

TPOC: Robert Mantz
Phone: (919) 549-4309
Fax: (919) 549-4310
Email: robert.a.mantz@us.army.mil

A10a-T012

TITLE: Random Number Generation for High Performance Computing

TECHNOLOGY AREAS: Information Systems

OBJECTIVE: The objectives of this STTR are to investigate numerical methods for scalable random number generators, and to develop algorithms and computer software that can be implemented for military and commercial simulation applications.

DESCRIPTION: Monte Carlo simulation has proven to be an indispensable technique for developing robust models over both low- and high-dimensional parameter spaces, helping simulation become widely recognized as the third major component of scientific discovery and development, co-equal with experimentation and theory [1,2]. With the advent of scalable parallel processing architectures, the need has become apparent for random number generators (RNGs) that are both parallel (capable of executing on multiple processor threads simultaneously without coherence) and scalable (capable of running on a variable number of processors, currently into the thousands and in the near future into an order of magnitude more, without coherence). Most modelers are aware of the danger of coherence in RNGs: stochastic models generate results with high degrees of periodic correlation between sections of output, reducing multiple runs to just replications of a small number of runs [3,4]. In the worst case, this can effectively reduce the number of trials to just one, and is even more dangerous since the coherence is often masked in the high dimensionality of the problem and is not easily noticed. While some work has been done in parallel RNGs (e.g. [5,6,7,8,9,10,11,12,13]), all of the results to date appear to be particular to a given architecture and size, and are not universally scalable or distributed. What is needed is development of a scalable implementation encoded in a standard software routine or set of routines that can be distributed within standard high performance computing (HPC) libraries for Monte Carlo computations and stochastic simulation on parallel, distributed, and Grid-based computing platforms. To ensure the integrity of simulations and prevent the introduction of inadvertent coherence between multiprocessing threads in military and commercial simulations, it is imperative that 1) the various existing parallel RNG techniques be investigated; 2) efficient numerical methods and their algorithms be developed for generating non-coherent random sequences over parallel threads; 3) prototype computer software for the algorithms be developed for military and commercial applications in HPC environments. In order to transfer the technology for commercial use, it is proposed that business technical staffs and university researchers be involved in both the investigation of the numerical methods and the development of the software. It is proposed that the program be carried out in the following two phases.

PHASE I: In Phase I the following shall be accomplished:

- a. A complete assessment of currently available numerical methods and algorithms for parallel random number generation.
- b. Development of random number generators for use on multi-core processors. This will include extensive support for pseudorandom number generation.
- c. Development of random number generators for use on General Purpose Graphics Processing Units (GPGPUs), which are now widely available on high-end graphics cards.
- d. Establishment of the bias, degree of independence, and the amount of coherence present in sequences generated on parallel threads.
- e. Development of new algorithms that are suitable for real time parallel and/or distributed computing environments.

PHASE II:

- a. Computer coding of the algorithms developed in Phase I shall be done primarily by software engineers in private industries and some by university researchers.
- b. Statistical methods such as chi-square testing, frequency testing, and correlation and autocorrelation testing shall

be employed to test for statistical randomness both within and between threads.

c. Release of a standard HPC version with licensing requirements for commercial users that incorporates the multi-core and GPGPU algorithms.

d. A complete set of documentation regarding the theoretical results, software design, and implementation shall be delivered with the prototype software to the military for evaluation and implementation at US Government HPC centers, including DoD Major Shared Resource Centers. It shall also be made commercially available to HPC users at academically oriented HPC centers.

e. A long-term sustainability plan for development, maintenance and support of the software on revenue estimates will be developed.

f. A website will be launched for the distribution and support of the software to both commercial and noncommercial users.

g. A stable support infrastructure to deal with both new and existing users will be created. Support will be maintained that is capable of dealing with installation issues over many platforms, as well as bug resolution and usage issues with the existing code base. This will not only include standard release mechanisms, but also a web-based help center that directly interacts with users.

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KEYWORDS: pseudorandom number generation, quasirandom number generation, parallel Monte Carlo, distributed simulation, high-performance computing, multi-core processors, GPGPU

TPOC: Dr. Joseph Myers
Phone: (919) 549-4245
Fax: (919) 549-4354
Email: josephd.myers@us.army.mil
2nd TPOC: Dr. Mou-Hsiung (Harry) Chang
Phone: (919) 549-4229
Fax: (919) 549-4354
Email: mouhsiung.chang@us.army.mil

A10a-T013 **TITLE:** Compact & Ultra-High Resolution Terahertz Spectroscopic/Fingerprint System

TECHNOLOGY AREAS: Chemical/Bio Defense, Sensors

OBJECTIVE: Develop a compact, tunable, terahertz (THz) frequency source/detector system that offers ultra-high resolution and room temperature operation over the 1 - 3 THz range. To provide high resolution molecular fingerprint information, the effort should leverage the advantages of novel wave-guiding methodologies to realize a THz source linewidth of 2 MHz or better while providing for 2 decades of dynamic range or better.

DESCRIPTION: While the Far-IR (THz) is nominally defined from ~ 0.3 - 10 THz (1 millimeter > wavelength > 30 micrometers), the frequency range above 1 THz provides a unique spectroscopic probe of the low frequency vibrational modes of materials. A wide variety of molecular properties, from the tertiary structure of proteins and polynucleotides [1] to mechanisms of ozone depletion [2], can be characterized by their modal spectra. The understanding gained from exploring the molecular dynamics of materials in this electromagnetic window will advance our understanding of basic material properties, as well as enable new applications such as non-destructive detection of complex chemical and biological agents [3], environmental monitoring [4], and advanced communications [5].

Such molecular-specific spectroscopy or "fingerprinting" requires spectral resolution at or below ~ 2MHz, a spectral range which extends to several THz, and frequency tunability. The availability of low loss nonlinear optical materials, together with the commercial availability of powerful, compact, tunable lasers, makes all-optical processes, such as difference frequency generation (DFG) and related processes (optical parametric oscillation, and stimulated polariton scattering), more practical than some types of electrical sources of THz generation, such as the quantum cascade laser and traveling wave tubes. And, since the spectral width of the THz product is determined by the linewidth of the optical pumps (which can be ~ 10's kHz), high resolution THz spectra (chemical fingerprints) can be obtained without an intervening spectrometer between source and detector. However, difference frequency conversion with high spectral purity requires an efficient (preferably optical) process. High efficiency, in turn, requires strong confinement of the two optical pumps and of the THz product, good overlap of the 3 optical fields over a long interaction length, and maintenance of the spatial synchrony between the induced polarization wave, and the electromagnetic wave product (i.e. phase matching).

Therefore, optical wave-guiding appears to be a useful vehicle for optimizing all three of these elements. This observation is support by the fact that a normalized power conversion efficiency of 1.3×10^{-7} 1/W was recently reported [6] in a phase-matched guided-wave THz DFG structure. This represents a 23-fold improvement over the best previously reported results using bulk nonlinear optical material [7]. Motivated by this important recent demonstration, it is the goal of this project to initiative a research and development effort for a guided-wave THz source based on difference frequency generation (DFG), or a related second-order nonlinearity which exceeds the results reported in [6]. Approaches may include alternative second-order nonlinear processes, longer interaction lengths, and/or lower loss materials. It should be noted that, with sufficiently low waveguide losses, the power

conversion scales as the device length squared. In addition, the device should be tunable across a reasonable working frequency range (~ 0.5 THz), and be able to be integrated with similar devices to cover the important 0.3 - 3 THz range. It is expected that this project will also investigate the use of this same waveguide structure as a coherent detector - able to recover both intensity and phase information - by employing the complementary DFG process. Here, an upconverted detected signal obviates the need for low-temperature bolometric detectors, and they should not be a part of the research and development effort. Therefore, the successful demonstration of an efficient guided-wave THz source could then be immediately followed by a proof-of-principle demonstration of the viability of the structure as a phase-sensitive THz detector.

PHASE I: The Phase I effort should minimally produce a detailed design for a guided-wave based THz source for room temperature operation in the 1-3 THz range which provides for a spectral width of < 2 MHz, and an output power sufficient for a 100:1 dynamic range, using a complimentary (i.e. based upon a waveguide structure/device similar to the source) room temperature detector (e.g. ~ 1 mW). Relevant technical evidence (i.e. modeling and/or preliminary measurement) should be provided to suggest that the source concept will allow for sufficient tuning (e.g. ~ 0.5 THz) and that it can be extended using waveguide dispersion engineering to achieve further expansion of the tuning capability. The effort should also provide theoretical solutions and modeling estimates for an actual design implementation of an integrated array of sources (i.e. including optical pumps) that will meet, or exceed the output power requirements of 1 mW across the specified band, but have a footprint no larger than $60 \times 60 \text{ cm}^2$.

PHASE II: The Phase II effort should develop and demonstrate a full prototype for a THz-frequency spectroscopic fingerprinting system that employs both sources and detectors that utilize novel waveguide structures. This prototype spectrometer should provide for achieving spectral widths of < 2 MHz, and output power levels sufficient for demonstrating 100:1 dynamic range detection capability (i.e. ~ 1 mW) when operating across a significant portion of the THz band (e.g. ~ 0.5 THz) at room temperatures. Although not absolutely required, the Phase II effort would typically provide alternative design solutions for integrated arrays of sources that offer the potential for exceeding the prototype output power and bandwidth requirements while not exceeding a $60 \times 60 \text{ cm}^2$ system footprint. The Phase II effort is expected to provide a defense-relevant demonstration (i.e. and possibly conducted at a U.S. Army laboratory or center) of the ultra-high frequency-resolution capability, which will be planned through discussion with the relevant points-of-contact.

PHASE III DUAL USE APPLICATIONS: The successful development and demonstration of a prototype THz spectrometer/fingerprinting system with ultra-high frequency resolution and substantial dynamic range would address numerous applications in areas related to sensing threats, such as detecting and identifying chemical and biological agents including explosive and possibly radioactive compounds. Indeed, the technology would support an array of chemical, biological and explosive sensor programs flowing out of the U.S. Army Edgewood Chemical Biological Center (ECBC), the U.S. Defense Threat Reduction Agency (DTRA), and the U.S. Navy Explosive Ordnance Disposal (EOD), just to name a few. This type of advanced system with extended source and/or detection capability at THz frequencies would also have important relevance to ultra-high frequency and/or extended-bandwidth communications for both military, security and private-sector applications. The sensing and characterization advantages of this technology would also have relevance to a host of commercial applications such as medical diagnostics, chemical monitoring, semiconductor materials/devices characterization, and tissue burn analysis, just to name a few.

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KEYWORDS: terahertz frequency, waveguide devices, spectroscopic, fingerprinting, chemical and biological agent, explosives, detection

TPOC: Dwight Woolard
Phone: (919) 549-4297
Fax: (919) 549-4310
Email: dwight.woolard@us.army.mil

A10a-T014 TITLE: Plasmonic Nanoantennas for Single-Molecule, Surface-Enhanced-Raman-Scattering Based Sensing

TECHNOLOGY AREAS: Sensors

OBJECTIVE: To design, fabricate, and demonstrate a new class of plasmonic nanostructures for single molecule SERS for biological and chemical sensing

DESCRIPTION: Raman spectroscopy holds potential for a wide variety of DoD applications because many biological and chemical materials such as explosives, protein biotoxins and some microbial materials can not be detected by other methods such as binding affinity and fluorescent assays, while almost all these materials exhibit unique Raman spectra which can be utilized as fingerprints for direct molecular/material identification [1,2]. Raman spectroscopy, however, suffers from its weak signals because the Raman scattering cross section of molecules is about 10-12 orders of magnitude smaller than the fluorescent scattering cross section of laser dyes. Since the discovery of significant enhancements of Raman scattering by metallic surfaces or nanostructures, surface enhanced Raman scattering (SERS) has been explored in different fields. Especially, recent experimental observations have shown that that SERS enhancements in certain situations can go as high as 10^{14} times, elevating SERS to single molecular sensitivity [3-7]. This great potential of SERS, however, has not been materialized owing to the lack of plasmonic nanostructures that can not only provide extraordinary local field enhancements, but allow for a reproducible fabrication in large scale. Studies have shown that large field enhancements are usually localized at the nanogaps of dimmer nanoantennas and increase dramatically when the gap size is below 3 nm [5, 8]. Early single molecule SERS experiments are done typically with aggregates of colloidal nanoparticles where the "hot-spots" of enhanced local fields are obtained only by chance and not controllable [3-7]. The particular challenge to achieving repeatable and controllable SERS active substrates originates from the difficulty to fabricate nanogaps controllably in large scale. Recent studies in plasmonics have led to better understanding of surface plasmon resonance and local field enhancements that promise novel designs and large-scale fabrication of single molecule SERS active substrates. For example, a variety of designs of optical nanoantennas have been proposed and demonstrated. Particularly, by varying the geometric parameters of these plasmonic nanoantennas, local field enhancements and plasmon resonances can be fine tuned [9-11]. Moreover, by confining molecules within the nanogap between two metal electrodes, SERS and molecular electronic measurements can be combined [12, 13]. This kind of redundant sensing mechanism promises not only minimizing sensing false alarms, but also a new way of seeking fundamental understanding molecular electronics.

In order to obtain repeatable substrates for single molecule SERS for sensing applications, this project will investigate the design of new plasmonic nanostructures with large local electromagnetic field enhancements; fabricate and fully evaluate their SERS enhancements factors; and quantify repeatability and controllability of such SERS active substrates. The ultimate goal of this project is to define a new class of plasmonic nanostructures which are highly effective for SERS-based sensing and that possess the scalability and reproducibility characteristics (i.e.

when produced by available nanomanufacturing technique) required for realizing large sensor arrays with extremely uniform properties. Here, it will be adequate to address single-wavelength operation within the nano-sensor arrays, but the work will be expected to address the design considerations required for operation at alternative frequencies. Furthermore, projects that wish to target the development of nano-sensor arrays that utilize multiple types of excitation sources are acceptable, but not required.

PHASE I: In the Phase I effort, a complete design of the plasmonic nanostructures with large local field enhancements ($E/E_0 > 100$) should be formulated, and the fabrication procedures should be developed for at least one device implementation. It is expected that the plasmon resonance frequencies and local field enhancements will be predicted as a function of the geometric and material parameters of the plasmonic nanostructures. The Phase I effort should execute fabrication experiments and benchmarking that demonstrate an adequate capability for the meeting the expected challenges (e.g. feasibility of repeatable fabrication of less than 5nm gaps, precise placement of SERS molecules at the “hot-spots,” etc.).

PHASE II: In the Phase II effort, small arrays of plasmonic nanostructures with resonant frequencies coincident with the targeted laser wavelengths should be fabricated and their single molecule SERS should be demonstrated. The performances of the plasmonic nanoantennas should be fully evaluated in terms of SERS enhancement factors (EF). Single molecule SERS demonstrations are expected which suggest that a SERS enhancement factor requirement in the range 10^6 - 10^{14} must be achieved. Although the plasmonic nanoantennas will be designed to be functional at one specific laser wavelength, the project needs to deliver theoretical/experimental results that provide guidance regarding how the nanoantennas can be designed and fabricated for other excitation wavelengths.

PHASE III: This Phase III work will demonstrate scalability and repeatability of the proposed plasmonic nanostructures for single molecule SERS. Specifically, arrays of the proposed plasmonic nanostructures will be fabricated onto 1 inch wafers by technologies like nanoimprint lithography or other scalable nanomanufacturing techniques. These arrays of plasmonic nanostructures in the whole wafers can be designed and fabricated for single laser excitation wavelength. The goal for the scalability and repeatability is that the standard deviations for the enhancement factors should be within 10% over the whole 1 inch wafer. This new technology will have commercialization opportunities for such military relevant applications as detection of trace amount chemical, biological and explosive agents. This same technology would find dual-applications such as advanced laboratory components for scientific characterization studies; materials/process monitoring in commercial manufacturing; and ultra-fast data processing.

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KEYWORDS: plasmonic nanostructures, surface enhanced Raman scattering (SERS), sensor arrays, chemical detection

TPOC: Dwight Woolard
Phone: (919) 549-4297
Fax: (919) 549-4310
Email: dwight.woolard@us.army.mil

A10a-T015

TITLE: Photonic Amplifiers Based on III-nitrides Grown on Si Substrates

TECHNOLOGY AREAS: Sensors, Electronics

OBJECTIVE: To develop a new class of photonic amplifiers based III-nitride wide bandgap semiconductors grown on Si substrates. These photonic devices are to function in the 1.5 μm wavelength region and will enhance Army capabilities of communications and countermeasures.

DESCRIPTION: Research in silicon photonics has received much attention in recent years because of its potential to utilize well developed silicon processing technology. A broad range of linear and nonlinear silicon photonic devices have been demonstrated such as modulators, splitters, switches and detectors. However, the most important challenge in silicon photonics is the difficulty in producing electrically pumped light sources and amplifiers. The III-nitride semiconductor materials have demonstrated excellent properties for photonic devices operating in visible and ultra-violet regions. Ternary compounds of these materials, and doping with impurity elements, have also shown high potential for devices in infrared (IR) regions. On the other hand, silicon (Si) crystal materials are the mainstay of modern micro-electronic devices. However, due to its indirect energy band gap, Si crystals have very low quantum efficiencies for optical emission. In addition, recent developments in optical communication networks have increased the demands for the high speed and high density optical signal processing. Optical communication networks play an important role in the overall functioning of military weapons systems. Current technologies, predominantly constructed of fiber-coupled and discrete components, give the resulting communication networks a volume or "footprint" that is much too large for emerging military platforms. The integration of photonic devices onto a Si wafer is one of the most important technologies needing to be developed to provide significant enhancement in the military communication network capability. Fabrication of optical devices directly on a Si wafer has been a major challenge [1]. Most of the difficulties arise from the large lattice mismatch between the optical materials as III-V semiconductor compounds and the Si crystal. Recent trends have mainly focused on wafer-bonding of the optical materials onto the Si substrate was attempted. But, the crystal quality, as well as the photonic

device performance has been far from satisfactory. Therefore, accommodation of an optical device directly/monolithically onto a Si substrate remains a pressing technological issue.

In Japan significant progress has been using in developing a reliable technology for growth of III-nitride photonic devices structures directly on Si substrates [2]. This technology anisotropic etching of the Si crystal to reveal areas in which III-nitride semiconductor materials can be grown with minimum lattice mismatch. Based on this approach, low loss optical waveguides and high quality light emitting diodes have been demonstrated. By exploiting a high quality AlN epilayer on Si as a template, the growth of III-nitride photonic structures on large area Si substrates up to 6-inch has been demonstrated [3].

PHASE I: Proof-of-concept of a technology for growth of III-nitride photonic device structures on (001) Si substrates is to be demonstrated. Novel photonic amplifier devices, involving ternary compounds or impurity doped, thin films are to be designed. Prototype, electrically pumped, optical amplifiers active at 1.5 μm are to be fabricated. Appropriate processing steps are to be determined and device measured.

PHASE II: Based on results from Phase I, the reliability of the technology for growth of III-nitride photonic amplifiers structures on (001) Si substrates is to be demonstrated various etching techniques and growth parameters are to be determined to produce efficient fabrication procedures compatibility with the standard complementary metal-oxide-semiconductor (CMOS) processing. Design of novel device structures needs to be completed, as well as selection of ternary or impurity doped III-nitride materials. Performance characteristics of III-nitride photonic amplifiers on Si will be measured.

PHASE III: Dual Use Applications: This effort will produce electrically pumped, optical amplifiers active at 1.5 μm . The fabricated devices are to have performance characteristics comparable or superior to other approaches. The development of the technologies for the growth of these III-nitride devices on (001) Si substrates is expected to lead to widespread military applications including optical communication networks, IR countermeasures, optical signal processing, and free space communications. The same technology will find unprecedented civilian applications in telecommunication systems.

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KEYWORDS: optical amplifiers, gallium nitride semiconductor, silicon electronics

TPOC: John M. Zavada
Phone: (919) 549-4238
Fax: (919) 549-4310
Email: john.zavada@us.army.mil
2nd TPOC: William W. Clark
Phone: (919) 549-4314
Fax: (919) 549-4310
Email: william.w.clark@us.army.mil

A10a-T016

TITLE: Filter-Free Concentration of Pathogens from Water Supplies

TECHNOLOGY AREAS: Chemical/Bio Defense, Biomedical

The technology within this topic is restricted under the International Traffic in Arms Regulation (ITAR), which controls the export and import of defense-related material and services. Offerors must disclose any proposed use of foreign nationals, their country of origin, and what tasks each would accomplish in the statement of work in

accordance with section 3.5.b.(7) of the solicitation.

OBJECTIVE: Develop a filter-free, reagent-free, hands-free system for concentrating pathogens from large volumes of potable water supplies.

DESCRIPTION: Detection of pathogenic microorganisms in potable water requires the capture, concentration and recovery of pathogens to deliver to a detection technology (e.g. Raman, FTIR, PCR, etc). Technology is sought that provides a filter-free method for capture of pathogens, requires no added reagents, and does not require change-out of components for sample delivery to a detection technology. Such a technology would provide the means of real-time sampling of large volumes (1000 liters) of potable water supplies with minimal power or logistical requirements.

PHASE I: Design and build a small-scale (approximately 1Liter/minute) laboratory breadboard system for concentrating pathogens from potable water supplies. Determine throughput and collection efficiency of *Bacillus* spores for a single-pass collector with the goal of providing a concentration factor of 2000:1 or better. Design a quarter-scale fully-integrated collection system that will be capable of processing 100-250L potable water in 30 minutes and result in delivery of at least 1000 *Bacillus* spores in <5mL of water as a result of processing 100L water spiked with 100 spores/L.

PHASE II: Build a prototype quarter-scale system that incorporates all needed design elements for concentrating pathogens from potable water supplies and delivering to an arbitrary detection technology. Demonstrate processing of 100-250 Liters of potable water in 30 minutes; demonstrate collection of least 1000 *Bacillus* spores with delivery in <5mL of water as a result of processing 100L water spiked with 100 spores/L. Demonstrate 24-hour continuous hands-free operation of the collection system. Identify design requirements for full-scale system capable of processing 1000L in 30 minutes with at 2000:1 concentration factor. Identify suitable detection technologies for integration to a Phase III system.

PHASE III/ DUAL USE APPLICATIONS: Build a full-scale collection system capable of processing 1000 L potable water in 30 minutes; integrate to a reagent-free detection technology (e.g. Raman, FTIR). Field-test the complete collection/detection system. First responders such as Civilian Support Teams and Fire Departments have a critical need for a small, reagentless biological warfare agent detection system. Such a system would be ideal for protecting community water supplies, or tracing outbreaks of water-borne pathogens such as *E. coli* or cholera.

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KEYWORDS: pathogen concentration, potable water, filter-free, reagent-less, bacillus, anthrax

TPOC: Dr. James Jensen
Phone: (410) 436-5665
Fax: (410) 436-1120
Email: jim.jensen@us.army.mil
2nd TPOC: Janet Jensen
Phone: (410) 436-5836
Fax: (410) 436-1120
Email: janet.jensen@us.army.mil

A10a-T017 TITLE: Benign, Inexpensive Simulant for Testing of Biological Standoff Sensors

TECHNOLOGY AREAS: Chemical/Bio Defense, Sensors

OBJECTIVE: To develop inexpensive, environmentally friendly simulants for testing of standoff sensors. To improve reproducibility and quality assurance in testing of standoff sensors. To design and produce a new generation of benign biological simulants which mimic the physical and optical properties of biological agents. The simulants would be used in the development of new optically-based standoff and point biodetection systems.

DESCRIPTION: New simulants are needed for the development of new sensors within the DOD chemical and biological defense community. In particular, outdoor testing is required to validate the next generation of standoff biological sensors. Environmentally friendly approaches to outdoor testing are needed that will provide the necessary data to validate the performance of new standoff sensors with minimal impact to the environment. Benign simulants are needed to facilitate outdoor testing of the next generation of early warning sensors that are needed to protect DOD personnel from a biological attack,

In many instances biological simulants that are currently in use are microorganisms that are similar in nature to a more dangerous organism that they are meant to simulate. The simulant microorganism is chosen such that it has minimal impact on the environment while providing maximum safety to all participants of the outdoor test. In the case of standoff detection testing, the simulant microorganism is chosen such that it has physical, optical, and spectral properties that are very close to the target microorganism.

However, there are problems associated with using one microorganism (live or dead) as a simulant for another microorganism. Current biological simulants are expensive. Synthetic simulants could provide significant cost savings. Releasing of large quantities of microorganisms into the environment may cause unintended consequences. In particular, at some future date the DOD may be required to remediate areas where microorganisms have been released in large quantities. Quality assurance with existing live simulants is a problem. Synthetic simulants would provide more reproducible testing with less variability. Synthetic simulants would be cheaper to maintain and control. Synthetic simulants could further reduce the environmental impact of outdoor testing.

This effort will focus on developing new environmentally friendly simulants whose optical and spectral properties closely match those of existing Bio-simulants (BG, EH, and MS2). Spectral properties will include, near-IR scatter, UV Fluorescence, Mid-IR absorption and LWIR absorption. Fluidizers can be added where necessary to make the aerosolization properties of the new simulants match those of existing simulants. Also, the physical properties of the

new simulants should match the physical properties of existing simulants as much as possible. Care should be taken to control the chemical composition of the new simulants such that an atomic absorption spectrum of a new simulants will match that of the existing simulants that they will replace. It is desirable to use eatable substances in the production of these benign simulants in this effort. Eatable substances generally have FDA approval, which will facilitate licensing efforts and reduce environmental impact.

This effort will focus on the development of inexpensive, environmentally safe testing methods for the next generation of standoff biological warfare sensors. Synthetic simulants have better quality assurance than natural products. This effort will provide for more reproducible standoff testing. Synthetic simulants are cheaper to maintain and control. This effort will also help the DOD to avoid potentially huge future remediation costs at some future date.

PHASE I: Explore the optical, spectral, and physical properties of common BW simulants. For this effort the emphasis should be placed on three common simulants: bacillus subtilis (BG), Erwinia herbicola (EH), and the MS2 Bacteriophage. Design a synthetic simulant material that matches the spectral features of current BW simulants over several regions of the electromagnetic spectrum. Materials made from food are sought after for this effort. However, small amounts of other chemicals may be required to achieve the necessary properties. Absorptions features of the new materials in the ultraviolet and the infrared regions (both mid wave and long wave) should match the spectra of existing simulants as closely as possible. The fluorescence spectra of the new simulant material should also match the fluorescence signature of the target materials. Near Infrared scatter of the new simulants should be examined and should match as closely as possible the target material. Aerosol properties of the new materials should be examined. The atomic absorption spectra of the new simulants should also match the AA spectra of the target materials as closely as possible. Demonstrate methods for producing small quantities of the synthetic simulants.

PHASE II: Explore methods for producing large quantities of the new simulant materials in a form that can be used for outdoor testing of standoff biological sensors. The ability to produce at least 100 kilograms of each simulant (BG, EH, and MS2 substitutes) should be demonstrated.

PHASE III: Spectral simulants can be used for calibration of biological sensors that would be used by first responders. Aerosols with well-defined spectral and optical characteristics would be useful to the scientific community.

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KEYWORDS: standoff biological detection, bacterial spores, aerosols, infrared spectrum, ultraviolet spectrum fluorescence, near-infrared scattering, atomic absorption spectra

TPOC: Dr. James Jensen
Phone: (410) 436-5665
Fax: (410) 436-1120
Email: jim.jensen@us.army.mil
2nd TPOC: Janet Jensen
Phone: (410) 436-5836
Fax: (410) 436-1120
Email: janet.jensen@us.army.mil

A10a-T018

TITLE: High Surface-area, Mesoporous Oxide Adsorbent Sampling System.

TECHNOLOGY AREAS: Chemical/Bio Defense

OBJECTIVE: The goal of this effort is to develop a high surface-area, mesoporous oxide adsorbent sampling system consisting of an infrared transparent microfluidic column for rapid detection of chemical contaminants in water. The primary purpose of this micro-fluidic approach is to mimic the behavior of solid phase extraction or chromatographic columns in terms of separation and concentration capabilities while providing a platform that is suitable for easy integration with an infrared-based detection system.

DESCRIPTION: The Joint Services have the need for a rapid detection of trace levels of chemical contamination in water systems. A simple, rapid detection system would help to minimize human exposure and limit potential environmental damage. The detection system must exhibit high sensitivity and selectivity while demonstrating the ability to discriminate high priority targets from a myriad of background interferences. Current and future activities in the military, homeland defense, and industrial arenas will rely increasingly on highly sophisticated and reliable detection systems for identifying and quantifying toxic materials present at trace levels in water-based systems.

The mid-infrared region (4000 – 400 wavenumbers) of the electromagnetic spectrum is widely utilized by scientists for both qualitative and quantitative analysis of chemical contaminants. Many organic molecules possess unique infrared fingerprints, which are readily distinguishable from the absorption patterns of common background signatures.

Fourier Transform Infrared Spectroscopy (FTIR), therefore, provides the selectivity that is required for a field detection system where a very low false alarm rate is needed. However, FTIR systems require pre-concentration in order to meet the sensitivity requirements of the DOD. Thus, there is a critical need for a simple and effective pre-concentration system that can be optimized for detection of trace quantities of chemical contaminants using infrared spectroscopy.

PHASE I: Design mesoporous materials that are optimized in their chemical and physical properties for adsorption of chemical agent simulants. Optimization will be accomplished by adjusting both the surface chemistry and the pore size of the oxide adsorbents. Selectivity will be incorporated into the oxide using a physical filter, which relies totally on size discrimination, combined with an adsorption filter, which relies on a chemical interaction between the analyte and the adsorbent.

PHASE II: Construct a microfluidic device that is optimized for the rapid concentration of trace amounts of chemical contaminants from water. Optimize the surface chemistry for the retention of a broad range of chemical targets in both surface and bulk regions of the device. A systematic approach for varying the surface chemistry of the oxides while simultaneously monitoring the retention strengths of various chemical targets will be required. Demonstrate the ability to integrate the pre-concentration system to an infrared spectrometer for rapid, reliable detection of trace chemical contamination in water supplies. The system will be demonstrated using solutions containing select chemical targets at very low concentrations. The contaminated water will be flowed through the device and the minimum detection limits and adsorption time determined using a standard infrared bench.

PHASE III DUAL USE APPLICATIONS: There are environmental applications for a robust, standoff chemical and biological sensor. A standoff sensor that can be used for detecting both chemical vapors and biological aerosols will significantly reduce the logistics burden on the Joint Services by reducing the number of sensors in the field. A rugged, inexpensive chemical sensor will benefit the manufacturing community by providing inexpensive monitoring of chemical and biological processes. Also, first responders such as Civilian Support Teams and Fire Departments have a critical need for a rugged, inexpensive sensor that can be transported to the field to test for possible contamination by CBW agents.

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KEYWORDS: chemical detection, mesoporous oxide, infrared spectrum

TPOC: Dr. James Jensen
Phone: (410) 436-5665
Fax: (410) 436-1120
Email: jim.jensen@us.army.mil
2nd TPOC: Janet Jensen
Phone: (410) 436-5836
Fax: (410) 436-1120
Email: janet.jensen@us.army.mil

TECHNOLOGY AREAS: Chemical/Bio Defense, Biomedical, Sensors

OBJECTIVE: Develop a passive infrared standoff sensor that is optimized for detecting biological aerosols.

DESCRIPTION: The Joint Services have the need for a small, lightweight, inexpensive sensor for standoff detection and tracking of biological aerosols. It has recently been shown that aerosolized bacterial spores possess a strong infrared signature that can be utilized by passive infrared sensors for detection and tracking of the aerosol plume. The infrared signature of aerosolized spores consists of an absorption component and a Mie scatter component. The absorption component that has been observed in remote sensing experiments consists mainly of the carbohydrate absorption band at approximately 1100 wavenumbers. However, aerosols also exhibit a Mie scattering component that is not present in the infrared signatures of chemical vapors in the environment. The Mie scattering component is primarily due to the reflectance of the cold sky off of the aerosol particles to the standoff sensor. The Mie scatter component is broadband extending into both the long-wave and mid-wave infrared regions of the infrared. Also, there is evidence that the Mie scattering component may possess a polarized component. Thus, passive standoff detection of biological aerosols may be enhanced by utilizing polarization techniques.

The goal of this effort is to develop a passive infrared standoff sensor that is optimized for the detection, identification, and tracking of biological aerosols. This system will provide early warning to the soldier-in-the-field of an attack by a biological warfare agent in aerosolized form. Possible solutions to the problem include differential polarization and dual band (long-wave and mid-wave) detection.

PHASE I: Perform an assessment of the theoretical sensitivity and sensitivity limits of passive infrared detection of aerosolized bacterial spores using passive infrared methods. Design a passive standoff infrared sensor that is optimized for the detection, identification, and tracking of biological aerosols. The goal of this program is to develop a system that can detect and track biological aerosol clouds from a standoff distance of up to 5 km with a discrimination range of 1 km or better. The desired detection sensitivity is 50,000 ACPLA (threshold)/ 10,000 ACPLA (objective) for a plume size of 200 meter or larger with a probability of detection of at least 80%. A performance model of the new system should be developed to predict improvements in performance. Data acquisition and signal processing of proposed system should be examined and modeled.

PHASE II: Based on a successful demonstration in the Phase I goals, design and build a passive standoff infrared sensor that is optimized for the detection, identification, and tracking of biological aerosols. The system should be built and optimized for field usage. The final system should be able detect and track biological aerosol clouds from a standoff distance of up to 5 km. The final system, including sensor, power supply, and display, should weigh less than 100 pounds and operate on a standard 110 volt, 20 amp power supply.

PHASE III DUAL USE APPLICATIONS: Further research and development during Phase III efforts will be directed towards refining a final deployable design, incorporating design modifications based on results from tests conducted during Phase II, and improving engineering/form-factors, equipment hardening, and manufacturability designs to meet U.S. Army CONOPS and end-user requirements. There are environmental applications for a robust, standoff chemical and biological sensor. A standoff sensor that can be used for detecting both chemical vapors and biological aerosols will significantly reduce the logistics burden on the Joint Services by reducing the number of sensors in the field. A rugged, inexpensive chemical will benefit the manufacturing community by providing inexpensive monitoring of chemical and biological processes. Also, first responders such as Civilian Support Teams and Fire Departments have a critical need for a rugged, inexpensive sensor that can be transported to the field to test for possible contamination by CBW agents.

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KEYWORDS: chemical detection, MEMS, infrared spectrum

TPOC: Dr. James Jensen
Phone: (410) 436-5665
Fax: (410) 436-1120
Email: jim.jensen@us.army.mil
2nd TPOC: Janet Jensen
Phone: (410) 436-5836
Fax: (410) 436-1120
Email: janet.jensen@us.army.mil

A10a-T020 TITLE: Topological Data Analysis and Wide Area Detection of Chemical and Biological Contamination

TECHNOLOGY AREAS: Chemical/Bio Defense

OBJECTIVE: Develop Topological Data Analysis tools for hyperspectral image systems. Apply these new tools to analyzing hyperspectral image data from newly developed chemical and biological wide area detection systems with the goal of enhancing the capabilities of the next generation early warning system.

DESCRIPTION: Topological data analysis is a new mathematical method to study massive data sets that arise in a variety of situations. There is an interest within the DOD chemical and biological defense community to apply these new methods to the problems of early warning of a chemical or biological attack. In particular, a new generation of passive infrared sensors for wide area detection of chemical and biological contamination based on hyperspectral imaging has recently become available. These new sensors may provide the next generation early warning system to protect DOD personnel from a chemical or biological attack. These new hyperspectral data systems generate massive amounts of data and have very high-volume data flows. Recent analysis of hyperspectral data from these new sensors has shown that analysis of non-linear effects can significantly increase sensitivity and detection capabilities. There is a desire to extend the analysis of non-linear effects to look for hidden, nonlinear, geometric structures and properties within the data as a means of further increasing detection capabilities.

Many important questions in data analysis of hyperspectral image data are qualitative in nature. For example, background estimation and image segmentation both require a fundamental understanding of the qualitative nature of the hyperspectral scene. Current statistical methods are ill-suited to detect such qualitative structures. It is essential to understand these non-linear properties before attempting to perform precise quantitative analysis, where

the differential radiance from a chemical or biological plume presents only a very small perturbation on the long-wave infrared signature of a hyperspectral scene. It is better to distinguish underlying data structures by understanding them qualitatively rather than relying completely on library comparisons and pattern matching. An understanding of the qualitative structure within a hyperspectral data scene will facilitate the development of new tools to exploit to extract important practical information.

PHASE I: Utilize topological data analysis techniques to analyze hyperspectral image data from a longwave infrared hyperspectral imaging sensor to look for hidden non-linear data structures and properties. In particular, examine chemical or biological plume data within hyperspectral image data scenes. Develop techniques for automated data analysis of hyperspectral image data.

PHASE II: Design and build a computer program for automated analysis of hyperspectral image data in the long-wave infrared region, with the goal of improving detection capabilities of chemical and biological plumes. Demonstrate improved detection capabilities using existing data using topological data analysis techniques.

PHASE III DUAL USE APPLICATIONS: The fundamental mathematical, computational, and statistical tools developed in this program will have broad impact across several avenues of defense application as the data sets amenable to the proposed analysis reside throughout the military. Examples include sensor, intelligence, biological, logistical, and other DoD-critical applications. Commercial applications of hyperspectral imaging include pollution monitoring and mineral exploration.

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KEYWORDS: topographical data analysis, hyperspectral imaging, optical sensing, signal processing, infrared spectroscopy

TPOC: Janet Jensen
Phone: (410) 436-5836
Fax: (410) 436-1120
Email: Janet.Jensen@attheArmy.mil
2nd TPOC: Dr. James Jensen
Phone: (410) 436-5665
Fax: (410) 436-1120
Email: jim.jensen@us.army.mil

TECHNOLOGY AREAS: Chemical/Bio Defense

OBJECTIVE: Develop a rapid assay for T-2 Toxin.

DESCRIPTION: The T-2 toxin belongs to the family of trichothecene mycotoxins that are produced by fungi. The T-2 toxin was first found in stored corn in 1971. Trichothecene mycotoxins are extremely hazardous to humans. Exposure to nanogram quantities of T-2 toxin can cause severe reactions. Central nervous systems injury, as well as gastrointestinal and hematological toxicity can occur from ingestion or inhalation of very small quantities of these toxins.

A very promising approach for the detection of trace quantities of trichothecene mycotoxins involves the use of 2-(diphenylacetyl)-1,3-indanedione-1-hydrazone (DIPAIN II) and its derivatives as reagents on solid supports. DIPAIN derivatives undergo significant fluorescence enhancement in the visible range under UV excitation when in contact with trichothecene mycotoxins. The presence of the toxin is indicated by the enhanced fluorescence of the DIPAIN derivative.

The goal of this program is to develop DIPAIN-derivative based test-strips that indicate the presence of trace quantities of trichothecene mycotoxins in aqueous solutions. The T-2 toxin will be used as a test case for this effort.

PHASE I: Examine the interaction of T-2 toxin (12,13-epoxytrichothec-9-ene-3,4,8,15-tetraol 4,15-diacetate 8-(3-methylbutanoate)) and DIPAIN-II (2-(diphenylacetyl)-1,3-indanedione-1-hydrazone). Design an assay in the form of a test strip that can detect 50 nanograms of T-2 toxin in less than 10 seconds using the enhanced fluorescence of the DIPAIN-II molecule or other suitable DIPAIN derivatives. Examine UV sources that are suitable for field usage that can be used to detect the enhanced fluorescence of the DIPAIN-II molecule.

PHASE II: Produce prototype test strips for detecting the T-2 Toxin using DIPAIN-II or other suitable DIPAIN derivatives. Design and build a hand-held ticket reader for detecting the ticket reader should battery operated and weigh less than 5 pounds. Demonstrate detection of 50 nanograms for less of the T-2 toxin on the test strip in 10 seconds or less. Examine methods for extending this technology to other trichothecene mycotoxins. In particular, examine methods where multiple toxins can be monitored on a single test strip in a multiplexed mode.

PHASE III DUAL USE APPLICATIONS: There are environmental applications for a rapid, inexpensive method to monitor for trichothecene mycotoxins in food and water. Food safety is essential to citizens of the US. Also, first responders such as Civilian Support Teams and Fire Departments have a critical need for a rugged, inexpensive sensor that can be transported to the field to test for possible contamination by toxins.

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KEYWORDS: trichothecene mycotoxins, DIPAIN, T-2 toxin, UV spectrum.

TPOC: Dr. James Jensen
Phone: (410) 436-5665
Fax: (410) 436-1120
Email: jim.jensen@us.army.mil
2nd TPOC: Janet Jensen
Phone: (410) 436-5836
Fax: (410) 436-1120
Email: janet.jensen@us.army.mil

A10a-T022 TITLE: Cooperative Deployment of Next Generation Chemical Standoff Sensors

TECHNOLOGY AREAS: Chemical/Bio Defense

OBJECTIVE: Develop the capability to acquire data from standoff sensors deployed on multiple moving platforms and fuse the data to provide real-time 3-D threat profiles.

DESCRIPTION: Passive infrared detection systems have proven very useful for standoff detection of chemical threats. Passive infrared systems usually operate in the longwave infrared region (8-12 microns) where distinctive signatures occur for many chemicals of interest to the chemical and biological defense community. Hyperspectral imaging systems have proven to be particularly good at monitoring for chemical vapors and providing protection over a wide area. Military spectroscopy systems exist that have been applied to the passive interrogation of CB aerosols and chemical vapors. These systems have shown great promise for the detection, identification and real time display of chemical vapor and aerosol clouds. However, much of the information obtained by these sensors (bearing and angular extent) does not match well with the current NBC-1 warning format. This limitation could hinder the ability of current hyperspectral systems to interface with the Joint Warning and Reporting Network (JWARN) system. In order to obtain the location and extent of chemical threat, information from multiple passive sensors is needed. Triangulation methods could then be used to provide location and extent of the chemical cloud and provide information that is more useful to the JWARN system.

Triangulation methods and tomographic reconstructions have been demonstrated using multiple hyperspectral sensors in controlled conditions. However, these approaches have been developed for use on well defined and flat test grids equipped with accurately pointed fixed sensors. Translating these abilities to sensors on the move will require some effort. Accurate triangulation requires accurate pointing and positioning information from each sensor, the ability to perform true 3-D tomography on uneven and partially obstructed terrain, as well as the ability to rapidly compute the profiles using capability appropriate for a battlefield environment.

The goal of this effort is to develop a system that may be useful to the Chemical Biological Defense Early Warning Strategy (CBDEWS) program. The proposed system should be capable of providing concentration profile updates at 90 second intervals with a spatial resolution of 30 meters at 5 km range and a detection threshold of 1 mg/m³ for a common chemical simulant such as triethyl phosphate. This effort will focus on the development of accurate pointing systems along with the software to integrate data from multiple sensors.

PHASE I: Conduct a trade study to assess sensor capabilities and develop derived requirements for pointing, positioning, and other metadata that are needed for determining the position of a chemical cloud from multiple moving platforms. The goal of this effort is to design a system architecture consistent with the Common Chemical Biological Radiological and Nuclear (CBRN) Sensor Interface (CCSI). Investigate computed tomography and

triangulation approaches appropriate for use with on-the-move-sensor data and demonstrate the feasibility of the approaches through simulation. Identify the computational resources required to achieve the required performance objectives. Develop exit criteria, conceptual design, and test plan for a prototype system to be developed in Phase II.

PHASE II: Construct a prototype system of an on-the-move cooperative passive sensor system. Existing sensors may be used or modified as needed. Demonstrate the ability of the system to determine chemical cloud location and extent from moving platforms. A chemical simulant such as a Freon may be used for demonstration purposes.

PHASE III DUAL USE APPLICATIONS: The First responders such as civilian support teams, fire departments, and military post-blast reconnaissance teams have a critical need for a rugged and versatile sensor system that can be transported to the field to test for possible CB contamination. This capability would allow first responders to map chemical contamination without the need to enter potentially contaminated areas, thereby avoiding needless threat exposure, as well as the need for decontamination. This capability will also allow the efficient use of limited resources and efficient treatment of those known to have been in an exposed area. This effort will facilitate the transition of the technology to those applications.

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KEYWORDS: chemical detection, chemical identification, hyperspectral, tomography, infrared, network, standoff, tracking.

TPOC: Dr. James Jensen
Phone: (410) 436-5665
Fax: (410) 436-1120
Email: jim.jensen@us.army.mil
2nd TPOC: Janet Jensen
Phone: (410) 436-5836
Fax: (410) 436-1120
Email: janet.jensen@us.army.mil

TECHNOLOGY AREAS: Chemical/Bio Defense, Sensors

OBJECTIVE: Develop a Narrowband microbolometer infrared detector for broad range detection and identification of toxic industrial chemicals and chemical agents

DESCRIPTION: The chemical and biological defense community has the need for a small lightweight sensor for detection of toxic industrial chemicals. Infrared absorption spectroscopy has proven to be a very useful tool in the detection and identification of airborne chemicals. Pattern recognition is used to compare the infrared spectrum of library molecules against the infrared spectra of airborne contaminants. In particular, chemical warfare agents and toxic industrial chemicals have distinctive absorption lines in the infrared region. Infrared spectroscopy has been used to detect chemicals at very low concentrations. Infrared spectroscopy also holds the promise of low false alarm rates due to the spectral pattern matching over a large number of spectral bins. Standoff infrared spectrometers have also shown promise in the area of standoff detection of liquid contaminants on manmade and natural surfaces. The size, weight, and power requirements of current infrared spectrometers have limited their utility in field environments. Current infrared spectrometers are too expensive to be deployed in large numbers.

Microbolometer devices hold the potential for significantly improving the chemical and biological sensing capabilities of the DoD. Microbolometer arrays are commonly used in thermal imaging cameras for military and commercial applications. These microbolometer arrays are typically broadband detectors. Individual microbolometer pixels absorb light across the entire infrared region, generating a thermal image. However, currently available broadband uncooled microbolometer arrays are generally not sensitive enough to perform low-concentration chemical detection. In particular, microbolometer arrays operating in the longwave infrared region (~ 8-12 μ m) are limited by the blackbody radiation limit.

Recently it has been demonstrated that the blackbody radiation limit only truly applies to broadband devices detecting radiation in the long-wave infrared (~ 8-12 μ m). For mid-wave (~ 3-5 μ m) detection and hyperspectral detection at any wavelength, the ultimate performance limits are far beyond those of the blackbody radiation limit. To date there has been very little research work in wavelength-selective uncooled devices. However, the initial studies have shown that a narrowband uncooled array could have significant improvements in sensitivity approaching the sensitivity of cooled infrared devices.

If a microbolometer is broadband or has a broad resonance, an integrated filter such as a Fabry-Perot cavity can be used to narrow the spectrum. This configuration may be preferred for narrowband applications. The system can be made tunable using electrostatic actuation. The goal of this program is to develop a narrowband microbolometer array that is suitable for chemical and biological sensing. To date, the long-wave infrared (~ 8-12 μ m) has shown the most utility as a chemical sensor; however, other regions of the infrared will be considered.

PHASE I: Design narrowband microbolometer devices for chemical sensing. For this application, a small number of pixels are acceptable. Determine suitable wavelengths for chemical sensing. Design a small lightweight chemical sensor that incorporates the microbolometer devices. This design should include an infrared source such as a glowbar and a sample cell for collecting samples of gas from the atmosphere. Model the proposed system and determine the sensitivity of the sensing device to a suitable chemical simulant. For this study, a Freon such as R-134a can be used. The goal of this effort is to design a sensor that can detect simulant vapors in the parts-per-million range.

PHASE II: Fabricate narrowband microbolometer pixels suitable for chemical sensing. Match the microbolometer devices with a source and possibly a small multipass optical cell designed for detecting trace amount of chemical simulants in the atmosphere. Assemble and test sensor. Characterize the sensor using ROC curve analysis and determine the ultimate sensitivity of the sensor.

PHASE III DUAL USE APPLICATIONS: There are environmental applications for a small robust, chemical sensor. A rugged, inexpensive chemical sensor will benefit the manufacturing community by providing inexpensive monitoring of chemical processes. Also, first responders such as Civilian Support Teams and Fire Departments

have a critical need for a rugged, inexpensive sensor that can be transported to the field to test for possible contamination by CW agents.

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KEYWORDS: chemical detection, MEMS, microbolometer, infrared spectrum.

TPOC: Dr. James Jensen
Phone: (410) 436-5665
Fax: (410) 436-1120
Email: jim.jensen@us.army.mil
2nd TPOC: Janet Jensen
Phone: (410) 436-5836
Fax: (410) 436-1120
Email: janet.jensen@us.army.mil

A10a-T024 TITLE: Sustainable Materials for Thermal Management of Base Camps

TECHNOLOGY AREAS: Materials/Processes

OBJECTIVE: To develop materials and processes for use in sustainable military base camps to: (1) provide sustainable power through harnessing solar radiation and (2) to provide air conditioning in hot climates through the use of thermoelectric devices embedded in flexible materials.

DESCRIPTION: Base camps require on-site electric power to carry out mission requirements. Also, personnel and

equipment within the base camps are susceptible to hot temperatures and humidity in extreme environments. However, future base camps must reduce their logistical burden for both the warfighter and the sustainment force. Emerging materials will be used in military base camps construction in hot climates to provide sustainable electric power through the use of high efficiency layered thin film photovoltaic devices incorporated on the surface of the materials, with the aid of thin film super-capacitors for efficient storage of electricity to be used non-sunlight hours. These solid state devices can be embedded in layered composite fabric that offer high stiffness/high strength to weight ratios and are durable in harsh environments. The power supplied by these devices can be used to drive air conditioning systems devices for comfort of occupants and thermal protection of critical electronic equipment, e.g. for Command, Control, Communications, Computers, Information, Surveillance, and Reconnaissance (C4ISR).

Additional thermal and humidity management of the enclosed tent space could be accomplished through thermoelectric devices, based on the Peltier effect, which act as solid-state active heat pumps. These Peltier devices can transfer heat from one side of the device to the other side against the temperature gradient (from cold to hot), with consumption of electrical energy, and can also be used to extract water from the air in dehumidifiers. The power to drive the Peltier devices would be derived from the integrated photovoltaic/super-capacitor system. The use of insulating composite fabric layers would help to insure thermal efficiency of the system.

The flexible materials would contain the both the photovoltaic devices and thin film super capacitors, along with Peltier devices. Any excess electric power can be connected to the electrical system and used to power electronic equipment.

The resulting materials would use light and heat from the sun to provide power and thermal management without the use of expensive and polluting fuels that currently run conventional generators. In addition, these relatively lightweight materials hold the promise to offset some of the weight burden of deploying heavy generators.

PHASE I: Conduct research on the materials and processes to integrate innovative solid state power supply and thermal/humidity management devices into materials for military base camps. For example, emerging thin film inexpensive polycrystalline silicon based photovoltaic devices and super-capacitors, along with thermoelectric devices could be embedded into composite layers of tent fabric to provide electric power for solid state cooling devices and other equipment. Investigate the use of layered composite fabric with high stiffness and strength to weight ratios and high durability in harsh environments (such as desert heat and wind-blown sand) that contain insulating layers to provide additional thermal management. Project the efficiency of the composite multifunctional materials for sustainable power and thermal management of base camp structures. Demonstrate the capabilities at the laboratory scale, and down-select the most promising technologies for further development.

PHASE II: Design and test high strength lightweight multi-layered, protective materials for construction of base camps that harness the light and power of the sun and provide thermal management for personnel and equipment in military critical facilities, such as Command Control Communication, Computer, Intelligence, Surveillance and Reconnaissance (C4ISR) equipment and facilities. Develop manufacturing methods to produce these layered materials, with the approach of scaling up to full sized smart sustainable base camp construction materials.

PHASE III: Commercialize multi-layered construction materials that incorporate power generating and thermal management components in non-military buildings and structures in industrial and environments. The resulting structural components would not only provide structural protection, but would also provide supplemental electric power to help offset energy supplied from the electric grid. In addition, the materials would be readily portable and could be used for tents used by campers in hot climates. The materials could help to revolutionize the refrigeration industry for storage of food and materials that must be kept at cool temperatures.

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concept,” Synthetic Metals, Vol 150, 2, pp.139-143, 2005.

KEYWORDS: base camps, thermal management, polycrystalline silicon, photovoltaics, super-capacitors, insulating layers, solid state devices

TPOC: Larry D. Stephenson
Phone: (217) 373-6758
Fax: (217) 373-7222
Email: Larry.D.Stephenson@us.army.mil

A10a-T025

TITLE: Field-Portable Enzyme-based Rapid Toxicity Test for Drinking Water

TECHNOLOGY AREAS: Chemical/Bio Defense, Biomedical, Human Systems

ACQUISITION PROGRAM: Office of the Principal Assistant for Acquisition, USAMRMC

OBJECTIVE: Develop a hand-held device using temperature stabilized enzyme-based technology that will respond rapidly and with appropriate sensitivity to a wide range of toxic chemicals in water while requiring minimal environmental controls for storage and use.

DESCRIPTION: As part of a research program to identify environmental hazards to soldiers resulting from exposure to toxic industrial chemicals (TICs), the U.S. Army Center for Environmental Health Research (USACEHR) is seeking new methods for providing rapid toxicity evaluation of water samples. Rapid toxicity test kits for water (e.g. EPA, 2006) can be useful for evaluating drinking water quality, but many tests have a limited capability for rapid response to a wide range of TICs (van der Schalie et al., 2006) and most utilize bacteria, yeast, eukaryotic cells, or whole organisms that require substantial control of environmental parameters (such as temperature) to facilitate reagent or test system shelf life, which limits use of the tests under field conditions. Enzyme-based kits, such as several tests for cholinesterase-inhibiting chemicals (such as carbamate and organophosphate pesticides) in water are available (Buehler, 2008), such kits are not designed for sensitivity to chemicals with a mode of toxic action other than cholinesterase inhibition, and many have reagents that must be stored refrigerated or frozen. Another commercially-available enzyme test kit, the Eclox test, uses temperature-stabilized reagents and has excellent shelf life characteristics, but in our testing only 1 of 12 test chemicals was detected in the desired sensitivity range (van der Schalie et al., 2006). Either additional single enzymes (Cowell et al., 1995) or a suite of enzymes (Arkhypova et al., 2001), may have promise for detecting a broader range of chemicals. Unfortunately, most test systems fall into two categories: sensitive, but not robust, or robust, but not sensitive. We are seeking innovative and creative research and development to provide an efficient, rapid screening tool using temperature stabilized enzymes for a broad range of TICs in water samples without interference from normal field water constituents while minimizing the need for environmental control of test storage and use conditions.

PHASE I: Conduct research to provide a proof of concept demonstration of a toxicity sensor device for water. The concept will be original or will represent significant extensions, applications, or improvements over published approaches. Design and performance considerations for a proof of concept demonstration are listed below. Note that because the recommended test chemicals are intended to represent a broader range of toxicants, analyte-specific sensors for these individual chemicals are not an appropriate solution to this topic.

1. The enzyme-based test system must be responsive to toxicity induced by different modes of toxic action representative of a broad spectrum of TICs. To represent a significant improvement over available test kits, the test system must respond within 60 minutes to at least 8 of 12 chemicals used by van der Schalie et al. (2006) at concentrations above the 7-14 day Military Exposure Guideline (MEG) levels for each chemical (USACHPPM, 2004), but less than the estimated human lethal concentration (van der Schalie et al., 2006).

2. Minimal time (30 minutes or less) should be required to prepare the test system and the biological component for use after a water sample is provided for testing.

3. The test system and its components, including consumables, should remain viable for at least six months without the need for temperature or other environmental controls.

4. The test system should require minimal processing steps and should be capable of being transitioned to a battery-powered hand-held device.

PHASE II: Expand upon the Phase I proof of concept demonstration to construct a hand-held prototype toxicity sensor device. Show the device sensitivity (with respect to the 7-14 day MEG concentration for water) and response rapidity (within an hour) with at least 20 chemicals with varying modes of toxic action for which MEGs and human lethal concentrations are available. Demonstrate viability of test system components under environmental conditions likely to be encountered in field testing. The device should have minimum logistical requirements and provide for straightforward data interpretation. Demonstrate that the device can function without false alarms in water matrices typical of Army field water supplies. Provide two toxicity sensor devices for independent evaluation and testing.

PHASE III: Evaluate the ability of the toxicity sensor device to identify the suitability of drinking water for deployed troops under field conditions. Field tests will involve testing at Army water production facilities. Military users include Preventive Medicine (PM) personnel at Level III PM Detachments, Level II Brigade Combat Teams, or other line units for whom the ability to rapidly detect chemical toxicity in field water will help accomplish their assigned water quality surveillance and risk assessment missions. This device will be an important component of the Environmental Sentinel Biomonitor (ESB) system for drinking water evaluation. Given current on-going concerns regarding accidental or intentional contamination of water supplies, this technology will have broad application for water utilities, as well as state and local governments. A well-formulated marketing strategy will be critical for success in these commercial applications.

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KEYWORDS: toxicity sensor, toxic industrial chemicals, drinking water, enzyme

TPOC: David E Trader
Phone: (301) 619-7626
Fax: (301) 619-7606
Email: david.trader@us.army.mil
2nd TPOC: Thomas P. Gargan, II
Phone: (301) 619-2338
Fax: (301) 619-7606
Email: thomas.gargan@us.army.mil

TECHNOLOGY AREAS: Biomedical

ACQUISITION PROGRAM: Office of the Principal Assistant for Acquisition, USAMRMC

OBJECTIVE: To develop a portable, compact, lightweight, rugged, low-powered (battery and electric), automated blood component separator (red blood cells, platelets, plasma) without requiring centrifugation, from single donor whole blood units.

The device should be able to automatically process one unit of whole blood (450 ml), within an hour, into plasma, red blood cells, and platelets without moving parts. It must use minimal or no disposables. It must include a means of self-sterilization. The device must be field-portable by one person.

DESCRIPTION: Hemorrhage is the leading cause of death of potentially survivable wounds. Severely injured casualties usually require very large quantities of blood, sometimes in multiples of the entire circulating blood volume in massively transfused patients. Current blood bank procedures process blood either manually or with automated component separators. Both methods rely on bulky centrifugation methods and are labor intensive. The single component separators (e.g. red blood cell, plasmapheresis, or plateletpheresis) are the size of an ice chest and weigh as much as 30 – 60 lbs. There are no portable, rugged, lightweight units that can separate all components of blood. Because of their short half-life, platelets must be collected in theatre for use in forward echelons of care in the military. Plateletpheresis is used, but it is only available in a mature battlefield and it takes up to 2 hours to collect platelets from one individual. Collection of a standard blood unit can be performed in 20 minutes, but then requires a blood bank laboratory for processing the components. In conditions of the dispersed battlefield, particularly in the early phases of war, a rugged, small, lightweight, low-powered automatic blood component separator would be useful for processing blood.

Recent work by Chen (2008) and Sollier, (2009) show that microfluidic techniques offers alternative methods for separating plasma from red blood cells than using centrifugation. The uses for these new techniques are suggested for plasma collection for point of care diagnostic instruments and produce only a small volume. This project topic is designed to test the feasibility and assist in the development of new techniques that can be miniaturized and produce blood components that meet the American Association of Blood Bank standards. These standards for human blood products include low hemolysis of red blood cells, high percent of purity of each component, normal platelet function parameters, sterility, etc.

PHASE I: To perform preliminary studies to assess the feasibility of the new microfluidic or similar technology to be used to separate whole blood into the components of packed red blood cells, plasma, and platelets from animal or human whole blood. Usually microfluidic technology uses or produces microliter amounts of fluid, rather than the 200 - 400 ml volume that is found in standard human blood component units. The objectives for this phase are:

- 1) to demonstrate that the device can produce pure undiluted components that keep the appearance of each component so that upon microscopic and/or functional evaluations (e.g., flow cytometry or coagulation function tests like thrombelastography or standard coagulation assays of prothrombin time (PT), etc.), there should be intact, discoid red blood cells with no hemolysis, non-activated platelets, and plasma that has no cellular components or hemolysis;

- 2) to demonstrate that the technique is scalable to a rate of 7.5 ml/min blood separated into purified components (This is the rate needed process one unit of whole blood into components within 1 hour).

The ideal design would be to have an intake of one catheter (either directly from a patient which would need to have appropriate citrate anticoagulant added, or from a unit of already collected whole blood) attached to the device with three ports exiting the device for collection into the components, maintaining sterility in a closed system. This phase will result in a proof of concept and provide preliminary data.

PHASE II: This phase should result in manufacturing a prototype device that is compact, rugged, lightweight, portable, and can automatically process one unit of whole blood (450 ml), within an hour, into plasma, red blood cells, and platelets. Ideally, this prototype should use minimal or no disposables (except for standard blood bags and additives) and include a means of self-sterilization. This device should be field-portable by one person. This prototype must produce blood components that meet all the American Association of Blood Bank criteria for human blood products as described above.

PHASE III: During this phase, modifications to the device will be complete and the final machine will be built. The device will have full capabilities for blood component separation and can be utilized by those civilian and military personnel who prepare blood components for use in patients, and have access to the storage refrigerators and safety testing.

Success of this project will lead to the development of a small portable device that can automatically process all the components needed. This capability will greatly facilitate blood collection in cramped and austere quarters such as a combat support hospital or a mobile blood drive units.

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KEYWORDS: human, blood components, plasma, platelets, red blood cells, automatic, portable

TPOC: Jill Sondeen
Phone: (210) 916-4331
Fax: (210) 916-2942
Email: jill.sondeen@us.army.mil
2nd TPOC: Michael Dubick
Phone: (210) 916-3860
Fax: (210) 916-2942
Email: michael.dubick@us.army.mil

A10a-T027 TITLE: Virtual Pedigree Template to Enhance Clinical Care and Research

TECHNOLOGY AREAS: Biomedical

OBJECTIVE: To develop a web-based software system to collect and manage genealogical information of any depth, level of complexity and extended family size that is linked to temporal (time-dependent) genomic, clinical, social, and environmental information contained within electronic medical records and clinical research management software. The software will connect with genomic data derived from a patient's biospecimens and annotations archived over time in a biobank. Stringent compliance with federal and state regulations on human patient privacy must be incorporated into the software. Pedigree data are useful for a wealth of research purposes in human population biology and genetics (1). Access to genealogical data will enhance decision-making in public health, clinical care of patients and biomedical research.

DESCRIPTION: The product will generate an overlay display, based on a template that interactively and iteratively changes the relationship descriptions between individuals based on who is identified as the "central" individual ("incident case"). The software will enable rapid and accurate construction and use application of extended pedigrees across multiple households and families by clinicians, geneticists and biomedical research scientists. The design and architecture will provide an intuitive graphical interface that can be adapted to many markets, with a framework and integrated functionality that readily updates with advances in medical practice and biomedical

research. The software will be designed to address several issues that existing pedigree tools cannot manage, including:

1) Simplification and greater flexibility in acquiring and recording genealogical data and timelines of critical events for large families, inter-related families, and extended families where parents have multiple partners with mixtures of children that are/are not related to other family members. Current software for genealogy capture and management are often modeled on automation/entry of hand-drawn pedigrees, so that it cannot adopt different relational vantage points when family members who are not 1st degree relatives must be added to the database.

2) Design of a specialized graphical user interface that focuses on an overview schema of the genealogical structures and related health data to enhance data capture, navigation, and visualization of family relationships by the user, to include:

- Pedigree capture, editing, and interaction performed with one major screen presenting a pedigree-like diagram, plus one major sub-screen with minimal controls;
- Elimination of inefficient confusing features, such as menus, complex screen navigation mazes, dynamically expanding diagrams, user scrolling, etc;
- Instant pedigree visualization of localized portions of any pedigree (including grandparents, uncles and aunts, step parents and half sibs, spouses and children with those spouses), centered around any individual in the database;
- Quick export of related individuals or portions of a family to standard pedigree drawing programs to create conventional pedigree diagrams for entry into a specific patient's EMR.
- Easy editing and updating of genealogical relationships.

3) Design will emphasize ease and flexibility of use. The underlying architecture should be compatible with leading health informatics models, methodologies, and standards including Health Level 7 (HL7), Clinical Data Interoperability Standards Consortium (CDISC), and the National Cancer Institute's Cancer Biomedical Informatics Grid (CaBIG).

Rationale: In the past, clinical phenotypes, such as poor eyesight, served as discriminators for deployment in the military. Within the foreseeable future, evaluation of health risks is likely to incorporate evaluation of genomic information that may determine susceptibility to disease. The current interest in epigenetics phenomenon where environmental exposures may modify DNA repair mechanisms and alter metabolism of toxic substances, and these changes may be transmitted across generations, has direct relevance to the military and their families, especially estimated 30-50% of military families who served over several generations (story examples: <http://www.defenselink.mil/news/newsarticle.aspx?id=54384>; and <http://www.defenselink.mil/news/newsarticle.aspx?id=54763>).

Currently, the Veterans' Database has no means to rapidly extract data on families to determine intergenerational associations that could be correlated with health outcomes and mortality to help guide health risk assessment. With today's concerns on intergenerational risks of exposures to combat warfare, electronic tools to access available clinical databases for search purposes are urgently needed.

Because the chemicals and toxic exposures of combat warfare have changed as more sophisticated weapons have been developed, descendants of a World War II soldier exposed to combat warfare, who chose military careers and may have served in Korea or Vietnam, may experience inter-generational epigenetic phenomena, that modulates health risks of the current generation serving in Iraq and Afghanistan. The change in social mores in recent decades have meant that one adult may change partners over time as marriages break up, and mingle children over two or more generations so that an uncle in one generation may be the same age as a child in the next generation. Display of equivalent timelines between generations is very difficult with today's tools, if not impossible. These social changes have profound implications in assessments of health risks based on common genetic variations, lifestyles that include smoking (70% of military are ever-smokers), cannabis and alcohol, and environmental exposures that may be naturally occurring, occupational or a consequence of exposure during combat warfare. The risks of traumatic brain injury and post-traumatic stress disorder (PTSD) that plague today's veterans and active military, are higher for those with traumatic childhood environments and dysfunctional families, whose risks are modulated in turn by common genetic variants, inter-generational lifestyle behaviors, and environmental exposures (2-8). Genealogical data may be even more useful in assessing later life risk of common chronic diseases, such as cancer. Physicians may treat related family members for the same disease with different treatment strategies, wasting resources and impacting quality of care. While rapid advances have been made in linking clinical and genetic data with biological specimens and outcomes using electronic medical records and clinical research data management software, the enrichment of these databases and improvement in decision making on risk assessment requires

powerful analytical tools to record and probe genealogy that currently do not exist.

PHASE I: Develop overall system design and health science architecture, create a prototype of the primary user interface for flexible pedigree data collection, and demonstrate initial range of functionality, with flexible capabilities to query, report, and export data. Design and architecture planned to enable customization and adaptation for a range of projects. The ability to work with large, multigenerational families including legal relationships that do not necessarily reflect a biological relationship should be demonstrated. The design and architecture will address the detection of attempted relationship assignments or alterations that could violate genealogical or genomic integrity. The design and architecture should comply with pedigree nomenclature from the Pedigree Standardization Task Force (PSTF) of the National Society of Genetic Counselors (NSGC) (9).

PHASE II: Implement the design and architecture developed in Phase I to create an operational version of the system, and field test the system. Explicit consideration of mutual influences between software and work practices will be part of the design process (10). Create forms for definition and collection of datasets, including, for example, genetics, environment, and demographics with relational and temporal links. Functions and usability aspects to include:

- Fixed positions of relationships to the central “focus person” to include cousins, and relatives across 3 or more generations (eg: active icons for great grandparents and for grandchildren, making genealogical data collection in real clinical settings easier through decreased requirement for iterative shifts of the central focus person);
- Multiple selectable options for genealogical coverage such that each level enables access to additional fixed relations to the central focus person (e.g. some users only need to see the parents and children section of the template, while others need the full multi-generational template to add, edit and analyze larger groups of relatives);
- Flexible, user-selected behaviors to manage links to relatives of an individual whose relatedness to the current focus person might need to be changed, because of new information or errors (eg: on user request, maintain links to spouses and children for a person whose relationship to the current focus person needs to be reassigned, vs. linking those spouses and children to some other individual);
- Options to add new relationship types and rules (e.g. handling legal relationships that may not be reflected in biological relationships, but which impact on use of pedigree information for purposes other than genetic analysis);
- Functions to enable large pedigrees to be merged;
- Detection and alert rules on attempted relationship assignments or alterations that could violate genealogical integrity (such as attempting to link an existing ancestor as a descendant);
- Selection of 2 or more people at the focus or at other fixed positions (such as spouses) on the template, with subsequent aggregate views of the relatives;
- The ability to open multiple pedigree templates with different focus persons, so they update when a change is made in any one of the templates;
- Provide researchers with a full range of item types (e.g. integer, float, date, string, options, measurement, multiresponse, scoring, tabular, text), and end-user capabilities for defining validation logic, skip logic, and notification logic when authoring data collection and deployment.
- Link a selected targets in a given pedigree to biospecimens and their related genomic databases to electronic medical records and clinical research management systems containing patient information, enrollment in research studies, informed consent tracking, and calendars of events related to research activities and/or clinical care. Integration with study protocols will allow researchers to develop a logical schema using common words and phrases found in clinical trials and a library of standard lab procedures.

PHASE III: Transition the prototypes and learning from Phase I and Phase II to comply with regulatory requirements on patient privacy and healthcare information technology standards and commercialize the operational system created and validated in Phase II, into a robust and scalable enterprise product.

Growing understanding of the contribution of genetic variation and environmental-induced epigenetic changes to disease, an expanding number of consumer-friendly genetic testing products, and the difficulty in widespread access to trained genetics counselors make it essential for clinicians and researchers to be able to rapidly and seamlessly collect, manage, and share genealogical information, an important goal in a wide variety of domains.

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KEYWORDS: pedigree data collection, extended pedigrees, software usability, functional integration, multilevel data collection, study protocol, biospecimen management, flexible data querying, applied health informatics, system evolution, genetics in society

TPOC: Amber Stanley
Phone: (301) 619-9977
Fax: (301) 619-7968
Email: amber.stanley@tatrc.org

A10a-T028 TITLE: Robotic Combat Casualty Extraction

TECHNOLOGY AREAS: Air Platform, Ground/Sea Vehicles, Biomedical

OBJECTIVE: To design, model, and prototype a near autonomous modular robotic combat casualty extraction system that can be readily implemented on any JAUS compliant military unmanned vehicle mobility system to pick up and extract wounded or otherwise injured personnel with minimal intervention by medic or other first responders operators within the varied array of operational environments of modern battlefields.

DESCRIPTION: Buddy treatment, first responder combat casualty care, and patient evacuation under hostile fire have compounded combat losses throughout history. Force protection of military first responders is complicated by increased involvement in peace keeping operations, counter terrorism, and humanitarian assistance missions that involve politically sensitive low intensity combat and combat in urban terrain; these operating environments may include urban or rough terrain covered by forests, jungles, mountains, marshes, snow or ice, and they may involve hostile threats posed by enemy fire or IEDs, contamination from weapons of mass destruction, or any of numerous natural hazards. For several years the Army has conducted or sponsored research in robotic casualty extraction and evacuation (CASEVAC), but has yet to solve the challenges posed by autonomously and safely picking up combat

casualties for the large number of body positions and locations at which casualties can be found. Autonomy or near-autonomy is needed in order to reduce or eliminate operator intervention and avoid distraction of soldier first responders from their primary duties. Significant research challenges remain in adapting, integrating, or developing new robotic technologies to approach, safely pick up and extract human patients to safety where they can be triaged, treated and further evacuated by medical or other first responders. In order to achieve near autonomous safe casualty pickup and short distance extraction and transportation of casualties over rough terrain to safety, additional research is needed in simultaneous and transparent control of robotic manipulator arms, end effectors, and mobility systems; finer movement control for those technologies, lighter weight, but stronger and quieter actuators or other robotic motor systems; coordinated robotic joint movement software; closed loop and/or near autonomous casualty monitoring and intervention, and integration of those devices with Joint Architecture for Unmanned Systems (JAUS) compliant agile military ground and air unmanned systems. If teams of unmanned systems are proposed then additional improved coordination and control schemes are needed. Specific technical research challenges remain in development of devices and algorithms or heuristics that constitute enabling technologies for unmanned casualty extraction and CASEVAC and mitigate associated medical risks: 1) plan and execute approach and regress routes within both urban and wilderness terrain, and without preloaded maps or terrain models; 2) communicate with and facilitate communications between patients and human medics; 3) execute command, control, and coordination of individual robots, robot teams, and medical payloads; 4) perform remote/stand-off initial casualty assessment to identify injuries sufficient to prevent further injury during robotic casualty extraction, 5) lift, move, drag, tow, or otherwise effect recovery of patients in any of numerous body positions from hazardous environments in any terrain to safe locations; 6) provide closed loop or semi-autonomous casualty monitoring and enroute care sufficient to mitigate risk associated with "abandonment" concerns during unattended CASEVAC, 7) plan and conduct recovery from errors or the unexpected. Focus of this effort should be on one or more of these types of technical challenges and associated enabling technologies.

PHASE I: Conceive and design conceptual and technical models which identify and translate functional requirements into implementable technical robotic patient recovery strategies and demonstrate feasibility of the concepts and capabilities designs. The resultant model or working laboratory prototype should show how a mobile robot and/or a robotic module implemented on a military mobile robot can safely pick up and transport a patient over rough or urban terrain (including steps) for short distances with minimal user-operator intervention. Develop a complete plan for a Phase II proof of concept demonstration and model validation.

PHASE II: Build and demonstrate a working prototype JAUS compliant robotic manipulator or team of robotic manipulators, which implements the model and demonstrates the concept in a prototype demonstration of the proposer's choice. The prototype should be able to be demonstrated as part or as a payload module on a military unmanned vehicle to lift and extract a full weight patient manikin from both rough and urban terrain models within minimal user-operator intervention. Maximum autonomy is desired.

PHASE III: Produce a ruggedized fieldable prototype system ready for demonstration and limited operational testing in military, as well as in civilian emergency response scenarios. Once validated conceptually and technically, the dual use applications of this technology are significant in the area of civilian emergency services for recovering injured personnel in mine, construction site and nuclear power plant accidents; chemical spills; fire fighting, terrorist, hostage situations; and, in police response to situations involving armed suspects. Commercialization of this technology could potentially save many lives among military and civilian emergency medical personnel, as well as among the casualties and injured persons they are assigned to help.

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KEYWORDS: medical robotics, casualty extraction & evacuation, CASEVAC, patient recovery, enroute care, combat casualty care, combat health service support, unmanned systems, robotics.

TPOC: Gary R. Gilbert
Phone: (301) 619-4043
Fax: (301) 619-2518
Email: gary.r.gilbert@us.army.mil
2nd TPOC: Craig Carignan
Phone: (301) 405-1996
Fax: (301) 619-2518
Email: craig.carignan@us.army.mil

A10a-T029 **TITLE:** Automated Support of Robotic Surgical Training, Operations, and Outcomes

TECHNOLOGY AREAS: Biomedical

OBJECTIVE: Develop a distributed, collaborative, automated platform that supports robotic surgical training, operations and outcomes.

DESCRIPTION: Concerns of quality, cost and access dominate national discussion of healthcare reform. Procedural complications are recognized as one of the most common adverse events afflicting patients and our healthcare system. Diverse data indicate a wide variance in performance of surgical procedures that negatively impacts quality, cost and patient safety. Furthermore, geographic disparity in surgical care indicates a shortage of skilled surgeons that will be increasingly felt by our growing, aging population.

Advanced information, robotic, and control systems could improve our national health system in the same manner that they improved civilian and military aviation. Information technology is ubiquitous and increasingly applied within medicine. Unfortunately, until the introduction of surgical telemanipulators such as the Intuitive daVinci Si “robot,” it was difficult to collect data of sufficient quality and granularity to significantly impact operative performance. Hundreds of thousands of robotic surgical cases are now performed annually and an opportunity exists to dramatically improve robotic surgical care through automation. Distributed, automated decision support would facilitate best practice by surgeons of all skill levels throughout the military health system.

This solicitation is focused on development of an automated system that collects and analyzes diverse data; identifies variances in operative care; and, provides clinically relevant decision support to improve performance and outcomes. Automated support could also include such capabilities as object avoidance, routine after action review, and adverse event investigation. Performance analysis at the surgeon, facility, command and military health system levels should define training needs, optimize care delivery and target development of enabling technologies (such as virtual reality simulator modules and automated performance of common, problematic tasks by the surgical robot). The open source system should be readily applied on currently available commercial and research surgical robotic systems. The proposed system should incorporate machine learning and thereby improve the quantity and quality of provided support with increased use and available data. The system should be flexible, scalable, interoperable, and secure enough for military use with the proposed Virtual Lifetime Electronic Records (VLER) and Nationwide Health Information Network (NHIN).

PHASE I: Conduct a detailed design and feasibility study to define a prototype automated surgical support system. Studies should evaluate information, robotic and control systems that could provide clinically relevant support and significantly improve robotic surgical operations and outcomes. The prototype system design should improve performance of tasks within a representative robotic surgical procedure (such as a robotic-assisted laparoscopic prostatectomy).

PHASE II: Based on the detailed design of Phase I, a prototype automated surgical support system should be

fabricated and demonstrated during Phase II. The performance of the prototype should be quantitatively tested and characterized. The evaluation data will be used to refine the initial prototype and improve system and surgeon performance of the selected surgical tasks and robotic surgical procedure.

PHASE III: Automated surgical support could improve operative performance and outcomes in a wide variety of military and civilian robotic surgical procedures. In this phase, detailed market analysis, application selection and commercialization will occur. Additional testing to meet FDA requirements will be completed and FDA clearances obtained. The successful system will be presented to the appropriate Army and DoD acquisition authorities for consideration of initiation of technology insertion into the Military Healthcare System. Additional funding may be provided by DoD sources, but the awardee must also look towards other government or civilian funding sources to continue the process of translation and commercialization. The automated surgical support system developed under this Small Business Technology Transfer (STTR) would significantly improve the quality, cost and safety of surgical care in the military health system.

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KEYWORDS: automation, neural networks, decision support, robotic surgery, simulation, comparative effectiveness, NHIN, VLER

TPOC: Timothy J. Broderick, MD
Phone: (513) 558-8670
Fax: (513) 558-3788
Email: Timothy.J.Broderick@us.army.mil
2nd TPOC: Amy Nyswaner, RN, BSN
Phone: (301) 619-1102
Fax: (301) 619-8135
Email: Amy.Nyswaner@tatrc.org

A10a-T030 TITLE: Tracking and Following for Mobile Robots

TECHNOLOGY AREAS: Ground/Sea Vehicles

OBJECTIVE: The objective of this program is to develop a passive vision system that will allow an unmanned

vehicle to autonomously follow a person or another vehicle.

DESCRIPTION: Currently, fielded unmanned ground vehicles are tele-operated, even in mundane operating conditions. This topic seeks to provide unmanned vehicles with the ability to reliably follow either a person or another vehicle. The system should operate without requiring any auxiliary material to be placed on the leader. The system is expected to use passive sensors and processing that are suitable for a vehicle as small as 20 Kg. The system is expected to follow from distances up to 50 m and at speeds up to 20 Kph. The system should allow for setting a specific distance offset and should operate in two different modes: drive towards the leader or follow the path of the leader. The system should be robust to temporary occlusions, should operate in GPS-denied areas, and in areas with multiple people and vehicles. It is acceptable for the system to be trained for a short period of time (less than a minute) with the operator designating the leader. When following a person, it would be useful for the system to recognize certain gestures for commands such as stop, go, faster, slower, closer, further.

There have been a number of research efforts at providing leader/follower capability, but many rely on special clothing, detection of faces or skin, specific human motion cues, or accurate range sensing, or are only intended for indoor use or from a stationary platform. This topic seeks a more general solution to the problem with larger follow distances, outdoor operation, and following both people and vehicles from a moving vehicle. The topic solution may require using motion cues, human or vehicle models, edge, color or texture features, geometric features, and/or motion prediction. If range sensing is employed, the system should seamlessly transition to other methods when the range sensing becomes unreliable. Research issues include finding an appropriate set of features that allow sufficient discrimination between similar objects while not being too computationally intensive, tracking the features, and adaptively adjusting the features as the distance and orientation between the leader and follower changes and as the background changes. While not a focus of this topic, integration of the leader/follower behavior with obstacle detection and avoidance will be necessary for a commercially viable product.

PHASE I: The first phase consists of investigating feature sets, tracking algorithms and video processing and showing feasibility on sample data. Documentation of design tradeoffs and feasibility analysis shall be required in the final report.

PHASE II: The second phase consists of a final design and full implementation of the system. At the end of the contract, person following and vehicle following shall be demonstrated indoors and outdoors. Deliverables shall include the prototype system and a final report, which shall contain documentation of all activities in this project and a user's guide and technical specifications for the prototype system.

PHASE III DUAL USE APPLICATIONS: Commercial applications include many UGV applications, such as security and inspection, service robots, virtual reality, and agriculture. Military applications include robotic mule, security and inspection, and convoy operations.

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KEYWORDS: leader-follower, robotics, feature tracking, person following, pedestrian detection

TPOC: Robert Karlsen
Phone: (586) 574-7530
Fax: (586) 574-6145
Email: robert.karlsen@us.army.mil
2nd TPOC: Robert Kania
Phone: (586) 574-5696
Fax: (586) 574-8684
Email: robert.kania@us.army.mil